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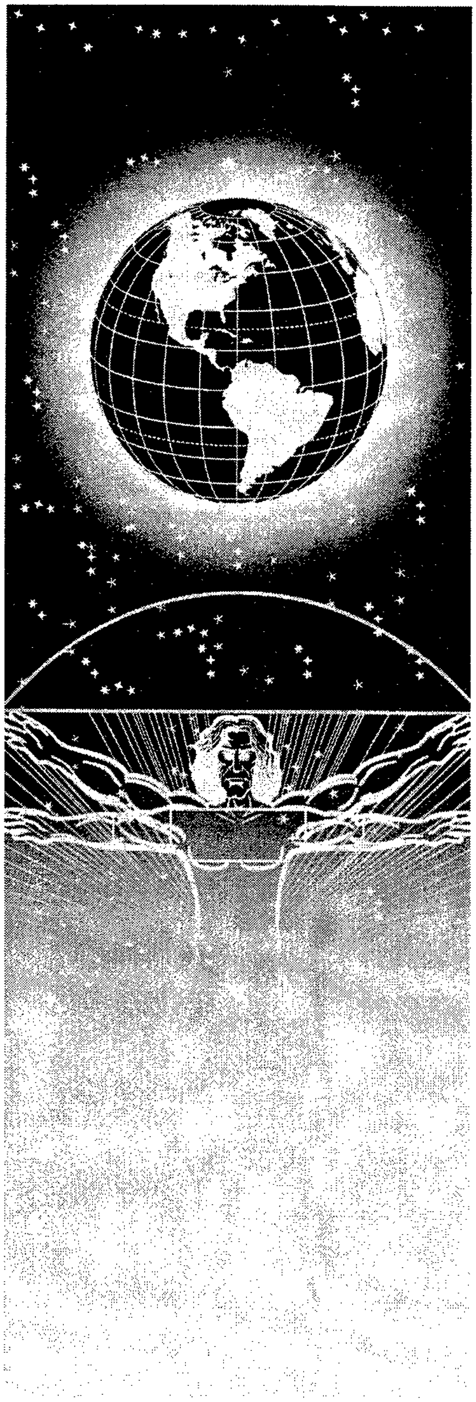

UNITED STATES AIR FORCE RESEARCH LABORATORY

ANTHROPOMETRIC RESEARCH ON THE SIZING OF THE MBU-20/P AIRCREW OXYGEN MASK

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NOTICES

TECHNICAL REVIEW AND APPROVAL

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Instruction 40-402.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

MARIS M. VIKMANIS
Chief, Crew System Interface Division
Air Force Research Laboratory

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13. ABSTRACT *(Maximum 200 words)*

The goal of this study was to determine sizing recommendation to improve the fit of the MBU-20/P Advanced Aircrew Oxygen Mask (AAOM). The approach was to do a fit test of the mask using the current sizes and the latest anthropometric measuring technology, then analyze the differences between subjects who passed and those who failed. This was done in conjunction with an effort to develop a customization process method for the soft rubber portion of the mask. This sizing study concentrates on improving the fit of the hard shell. The sizes currently available are SN (Small Narrow), MN (Medium Narrow), MW (Medium Wide), and LW (Large Wide). While it was hypothesized at the outset that the fit could be improved by adding a size, the fit results indicated that this was not the case. Instead, the location of the mask with respect to the face seemed to be an overriding factor.

14. SUBJECT TERMS

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EXECUTIVE SUMMARY

The goal of this study was to determine sizing recommendations to improve the fit of the MBU-20/P Advanced Aircrew Oxygen Mask (AAOM). Quality of fit is related to factors such as anthropometry, performance, and personal preference. Performance must be considered, because the quality of fit can change with usage. A mask with a good seal on the ground may break seal at high g. This is not an acceptable fit, so the size of the mask must be modified. Furthermore, some people are more tolerant of discomfort than others. A mask designed for two people with the same facial anatomy may be tolerable to one person and uncomfortable to another. An uncomfortable mask is a safety risk, so its size must be modified. What do you do when your suit doesn't fit? You take it to a tailor to have its size altered. Essentially, you have conducted your own fit test and have determined that the size is not right. When we see a lot of the same problems with fit, it is natural to want to know why the problem is there and what to do to fix it. Understanding the relationship of anthropometry to an acceptable quality of fit is key to making recommendations reqarding sizing. Fit testing is a method commonly used to take anthropometry, performance, and personal preference into account when making sizing recommendations. As such, our approach was to do a fit test of the AAOM mask using the current sizes and analyze the difference between subjects who passed the fit test and those who failed.

Thirty male and thirty female subjects were tested. The subjects were fit into the proper size by an expert fitter who evaluated the initial fit. After this they were measured and the fit of the mask was assessed. Twenty of the male subjects were from an active duty unit at Luke AFB. These subjects were fit tested after flying with the mask. The remaining men and all of the women were provided by AL/CFT at Brooks AFB. This location was selected with the intent that all subjects could be fit tested after having either flown or been taken to a high-G level on the centrifuge. Most of the male test subjects provided were fit tested after having been exposed to high-G. Unfortunately, only two female test subjects were provided that had ridden the centrifuge, and none had flight experience with the mask.

The results for both sexes indicate that Sellion to Supramenton Length distinguishes between sizes. This is to be expected as it is the size selection measurement used in the technical order (TO). The results for the males further indicate that the primary factor for quality of fit within a size is the placement of the mask on the face. There was evidence for this in all sizes. Furthermore, there were no statistically detectable differences in facial anatomy within a size between subjects who passed and those who failed.

While no anatomical differences were found, that does not mean they do not exist. It merely indicates two things: the scale of the effect due to placement was large in comparison to any possible anatomical effects and/or the fit data do not correlate well to the mask to face interface extracted from the scan. In either case, if there are any anatomical differences, they were undetectable. These conclusions were further supported by testing done by AL/CFT to compare sizes MN and MW. In that test all subjects who were re-tested in the same size changed overall fit score. In other words, when the same mask was put on a second time they got a different fit rating. A method was devised to help pilots ensure that they replace the mask in the proper position during routine use.

If anatomical differences are merely hidden by the other fit factors, we have no statistically significant evidence to describe them. Having no evidence for new sizes, anecdotal information from expert fitters was relied upon to make a judgment about the regions where new masks might be needed. Simple proportional growth differences between existing sizes was used to scale the three-dimensional changes needed to proportion the two new sizes. The old sizes were scanned and three-dimensional representations are available. The next step would be to create computer models of the new sizes. It is recommended that these new sizes also be tested.

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INTRODUCTION

The goal of this study was to determine sizing recommendations to improve the fit of the MBU-20/P Advanced Aircrew Oxygen Mask (AAOM). The approach was to do a fit test of the mask using the current sizes and analyze the differences between subjects who passed and those who failed. This was done in conjunction with an effort to develop a customization process method for the soft rubber portion of the mask. It has two basic pieces which affect fit, a hard shell and a soft rubber insert (face piece). The sizes currently available are SN (Small Narrow), MN (Medium Narrow), MW (Medium Wide), and LW (Large Wide). This sizing study concentrates on the hard shell.

METHODS

Anthropometry and fit data were collected from 30 male and 30 female subjects. The data was collected at Luke Air Force Base (Phoenix, AZ), 7 through 15 December, 1994, and at Brooks Air Force Base (San Antonio, TX), 31 January through 8 February, 1995. All of the female data came from the Brooks survey, while 20 of the male subjects came from the Luke survey and the remaining 10 males from the Brooks survey.

DATA COLLECTION

The overall data collection method is summarized in Figure 1 on the following page. First, the mask was fit by an expert fitter using the appropriate technical order (TO 14P3-1-161). The fit of the mask was verified by the fitter with the TTU/529-E tester using the appropriate technical order (TO 33D2-10-68-1). Adjustments to the strap lengths were made by the fitter until the subject was able to seal on the tester. For subjects not obtaining a seal on the tester, the fitter either ground the hard shell of the MBU-20/P mask or tried a neighboring size. The fit of the mask was again verified with the tester, and appropriate adjustments to the strap lengths were made. This fitting process was repeated until the fitter was confident that the subject had an acceptable fit in the mask. At this point the fitter completed the "COMBAT EDGE MASK GRINDING CHECKLIST" shown in Appendix A.

The next step in the process occurred along two parallel paths. Ideally, all subjects would have tested the fit of the mask in an operational fighter aircraft or a centrifuge. This was not possible, especially for the female subjects. Therefore, some subjects had no testing of the mask in an aircraft or centrifuge and did not experience accelerations above 1 G with the mask. The fit for subjects that did test the mask on an aircraft or centrifuge was then re-evaluated by an expert fitter. If the subject obtained an unacceptable fit with this operational testing, the subject recycled back to the fitter for strap readjustments, grinding of the hard shell, or trying a neighboring size. Those subjects that obtained an acceptable fit then reported to the Armstrong Laboratory Team for fit testing and anthropometric data collection. At this point, subjects should have had the best possible fit with the MBU-20/P oxygen mask.

The Armstrong Lab Team first briefed the subject regarding the remainder of the data collection steps. The briefing included obtaining informed consent from the subject. (The consent form used, "Protocol 83-30," is included in Appendix B.) Next, the subject was interviewed regarding the fit of their mask. The interview was structured around completion of a fit assessment questionnaire (included as Appendix C). Using the form, detailed information regarding fit in terms of comfort, slippage, and leaks was obtained. In addition, data was collected regarding the number of sorties or centrifuge runs the subject had completed with the mask and whether or not positive pressure breathing was used at G. Helmet size, mask size, and whether or not the mask had been ground was also recorded.

AAOM DATA COLLECTION FLOW

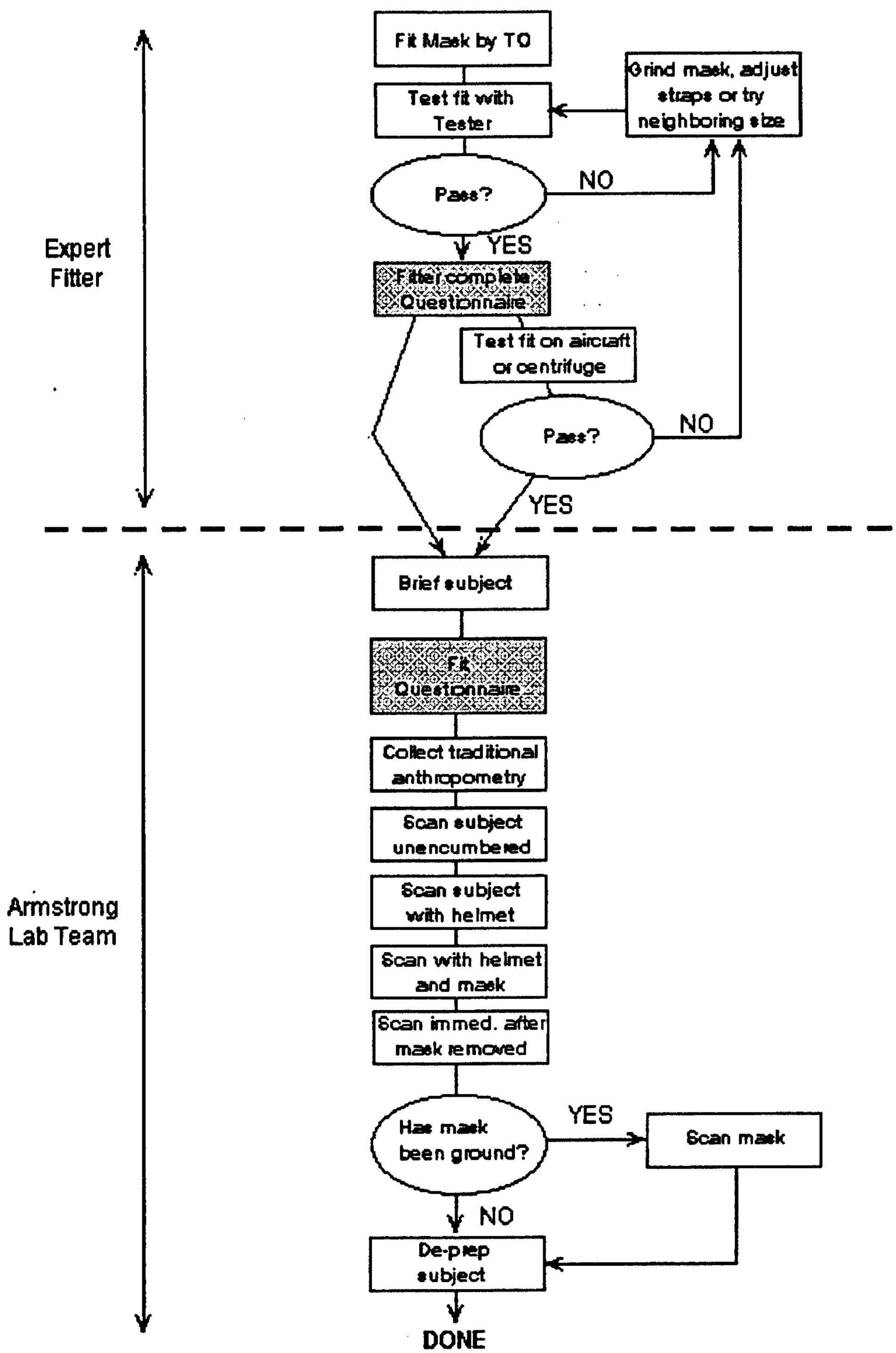


Figure 1. AAOM Data Collection Flow

Next, traditional anthropometric data were collected on each subject. The form "AAOM ANTHROPOMETRY" (Appendix D) was filled out to record the subject's traditional anthropometric measurements. Basic demographic data were also collected using this form. Subjects were first marked with 16 landmarks, as shown in Figure 2, with round, 1/4 inch, light blue, gummed-back stickers. Calipers and a steel tape measure were then used to collect 15 measurements prior to placement of a smooth, thin, rubber cap over the subject's hair. The cap was used to more accurately represent head shape during the scanning procedure. Three measurements were also taken after cap placement. Descriptions of the landmarks and measurements can be found in Appendices E and F, "Anatomical and Auxilliary Landmark Descriptions" and "Definitions of AAOM Anthropometry."

The next steps included scanning of the subject with a Cyberware 4020 RGB/PS-D Color 3-D Digitizer. The digitizer uses a laser and two cameras to record up to 130,000 points spaced approximately 1.5 mm apart on the surface of the subject's head and shoulders in approximately 17 seconds. The scanner records the location of each point in three-dimensional space, along with the color of the surface at each point. Four scans were obtained from all subjects, and a fifth scan was obtained from subjects with ground masks.

With the exception of the thin, rubber cap mentioned earlier, the subject was unencumbered (i.e., the subject was not wearing any life support equipment) for the first scan. The cap was removed for subsequent scans, but the blue stickers on the landmarks were present for all scans.

Next, the subject was scanned while wearing an appropriately fit HGU-55/P helmet. Three blue stickers were also placed on the helmet for subsequent data analysis.

For the third scan, the subject put their mask on as the expert fitter had instructed them to do. This represented how they would have worn the mask operationally. To facilitate data analysis, six blue stickers were placed on all masks, and a thin yellow piece of tape was placed on the ground edge of any mask that had been ground. The blue stickers were surrounded by a white, gummed back sticker with a 1/4 inch inner diameter and 9/16 inch outer diameter to increase the contrast between the blue stickers and the mask. The placement of the stickers can be seen in Figure 2.

The fourth scan was obtained within 30 seconds of removal of the mask, and without taking off the helmet. This scan was taken to secondarily record the mask placement by capturing the location of the red line (from reactive hyperemia) on the subject's face where the mask had been seated.

If the subject had a mask that had been ground, a fifth scan of the mask alone was made. In this scan, the mask was positioned so that the scanner would optimally record the shape of the ground surface.

Finally, the subject was debriefed regarding the study, and all blue stickers were removed.

SAMPLE SELECTION

After data was collected on a sample of 20 males at Luke Air Force Base, the sample was examined for gaps in the expected distribution. We compared the Luke sample to the 1967 Air Force Males, the 1990 Air Force Male Flyers, and the 1988 Army Males based on Face Length (Menton-Sellion Length) and Face Breadth (Bizygomatic Breadth). We used these comparisons to determine the dimensions and number of subjects we needed to sample at Brooks. Figures G1, G2, and G3 of Appendix G illustrate these comparisons indicating the sample actually collected at Brooks and Luke, as well as the number of subjects (within each box) we *intended* to sample at Brooks.

Since no female data were gathered at Luke, we prepared a sampling strategy before female data collection began at Brooks. The 1968 Air Force Females and a subset of women from that dataset who

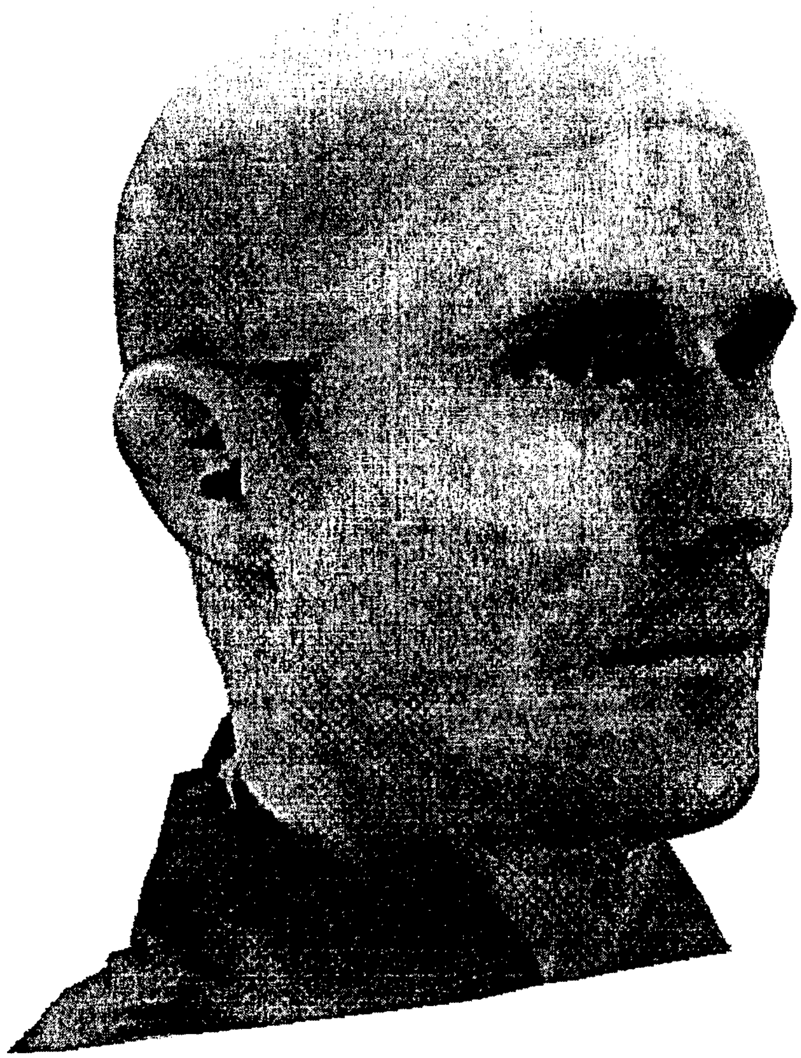


Figure 2. Palpated Landmarks

met pilot training entry requirements were examined (Figures G4 and G5 of Appendix G). The numbers inside the grid represent the number of women within each box that we intended to sample at Brooks.

The sampling strategy was based on an estimation of the percentage of subjects that fall within the "gaps" and an educated guess on the amount of data required to make sound conclusions. The figures show that we did not obtain the desired samples for men or women. The female sample is particularly void of women with smaller faces.

DATA PREPARATION

Before analysis of the three-dimensional surface scan data could begin, landmark locations (both anatomical and equipment-based) had to be digitized. Integrate, the CARD Laboratory's 3-D visualization, manipulation and analysis software (Burnsides, et al., 1995); was used to load each of the subjects' scans one at a time. Any voids in a data set were first filled by an interpolation routine. Voids are normally caused by a lack of reflection of the laser light from the scanned surface (e.g. due to extremely dark colors or a portion of the surface that is nearly tangential to the laser). Landmarks were then digitized by using a mouse to place the cursor over the center of the landmark, and then pressing the left mouse button. Once all landmarks of interest were digitized, the landmarks' three-dimensional coordinate locations were saved (cylindrical and cartesian) in a separate landmark file.

IDENTIFYING THE MASK TO FACE INTERFACE

Because shape information was viewed as a likely candidate for identifying fit differences, it was important to identify the location on each subject where the mask seal met the face. Locating this seal area required several steps of data manipulation. The first step was to load a scan of the appropriate size face piece into Integrate. Although scan data for the face piece was used in this step (as opposed to scan data from the hard shell), the two components are nearly identical in size and shape. Landmarks on the mask were used to align the mask into a standard position, hereafter referred to as the mask-axis system (Figure 3). The mask-axis system was defined as follows: The X-axis runs through the lower two landmarks on the front of the hardshell with the origin falling half-way between; the Y-axis is orthogonal to the X-axis and runs through the point half-way between the upper two hardshell landmarks; while the Z-axis is orthogonal to both the X and Y axes. In order to make comparisons between subjects, all scans had to be aligned into a common coordinate system: in this case, the mask-axis system. Scans of one encumbered subject at a time were loaded into Integrate and registered with the face piece (Figure 4). This was performed by finding the least-squares fit of landmarks in common to both datasets. The next step was to load the unencumbered subject's scan and register it with the encumbered scan using the same least-squares technique (Figure 5). Finally, the encumbered scan was deleted, leaving the unencumbered scan aligned with the face piece in the same position as the subject actually wore his mask (Figure 6).

In several cases, the least-squares registration routine did not work as described above. It was theorized that landmarks chosen on the masks were co-planar. Due to software restraints in Integrate, these landmarks could not be registered with another set of similar co-planar landmarks (it is best to define registration landmarks that clearly define three dimensions in order to fix any necessary data rotations and translations during the registration process). This difficulty was overcome by adding an extra step into the registration procedure. In order to "fool" the software into performing the necessary registrations, a different size mask was first registered with the correct size mask, followed by registration of the encumbered subject with the different size mask. The incorrect size mask was then deleted, leaving the correct registration between the encumbered subject and the correct size mask (this is a valid registration since the landmarks on the encumbered subject and those on the correct size mask are located in identical places). The scan of the unencumbered subject was then loaded and registered in the same manner described above.

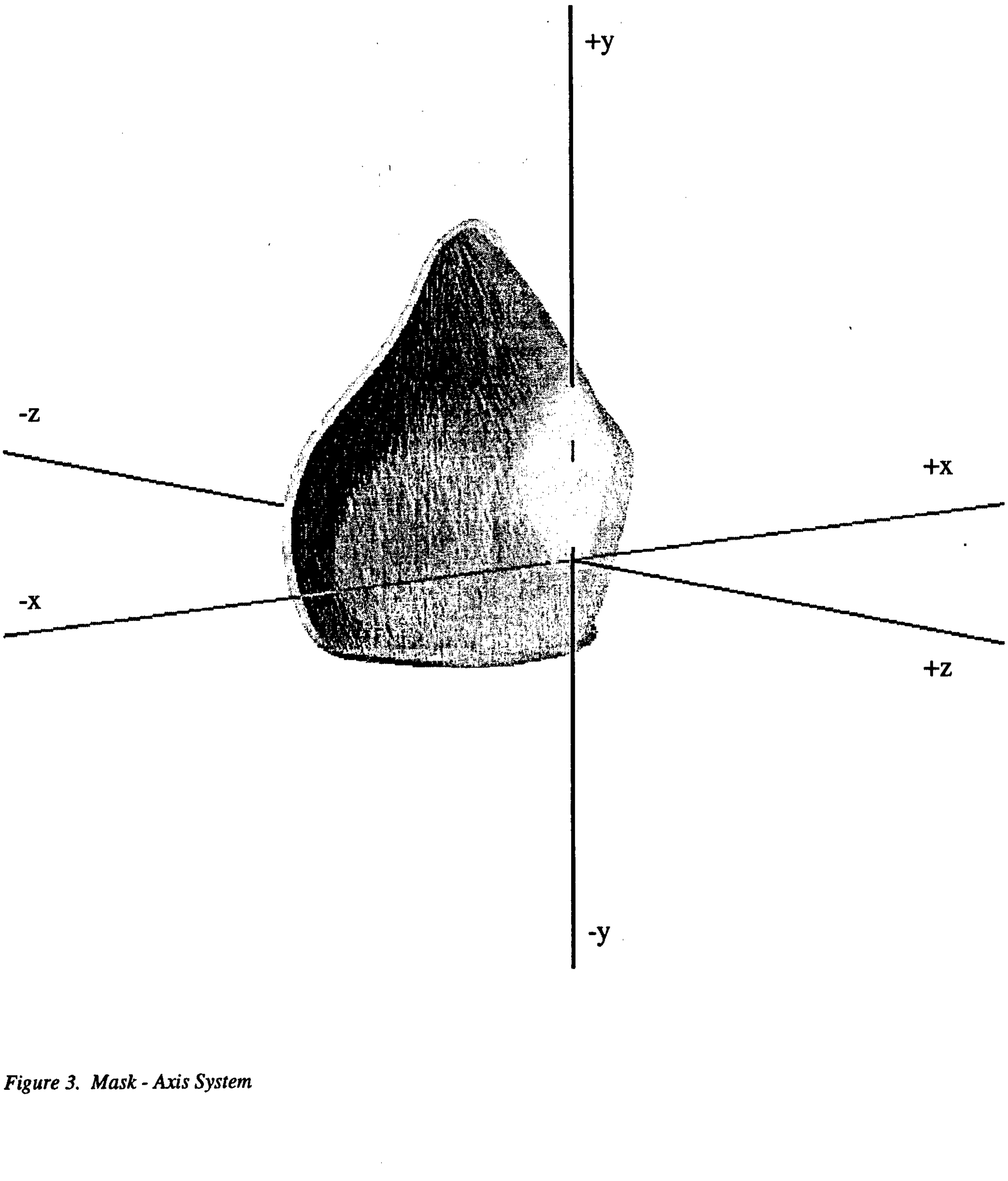


Figure 3. Mask - Axis System

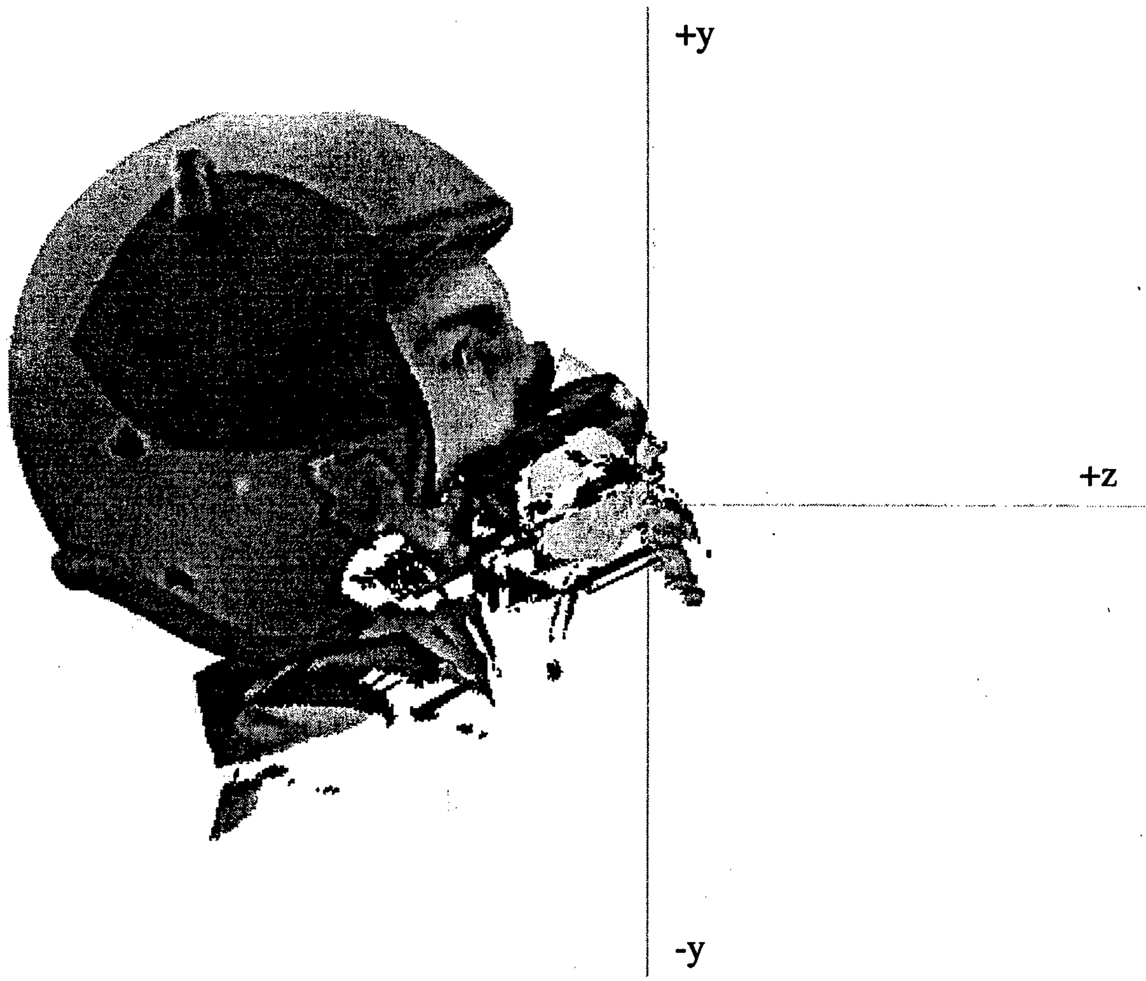


Figure 4. Encumbered Subject Registered with Mask (face piece)

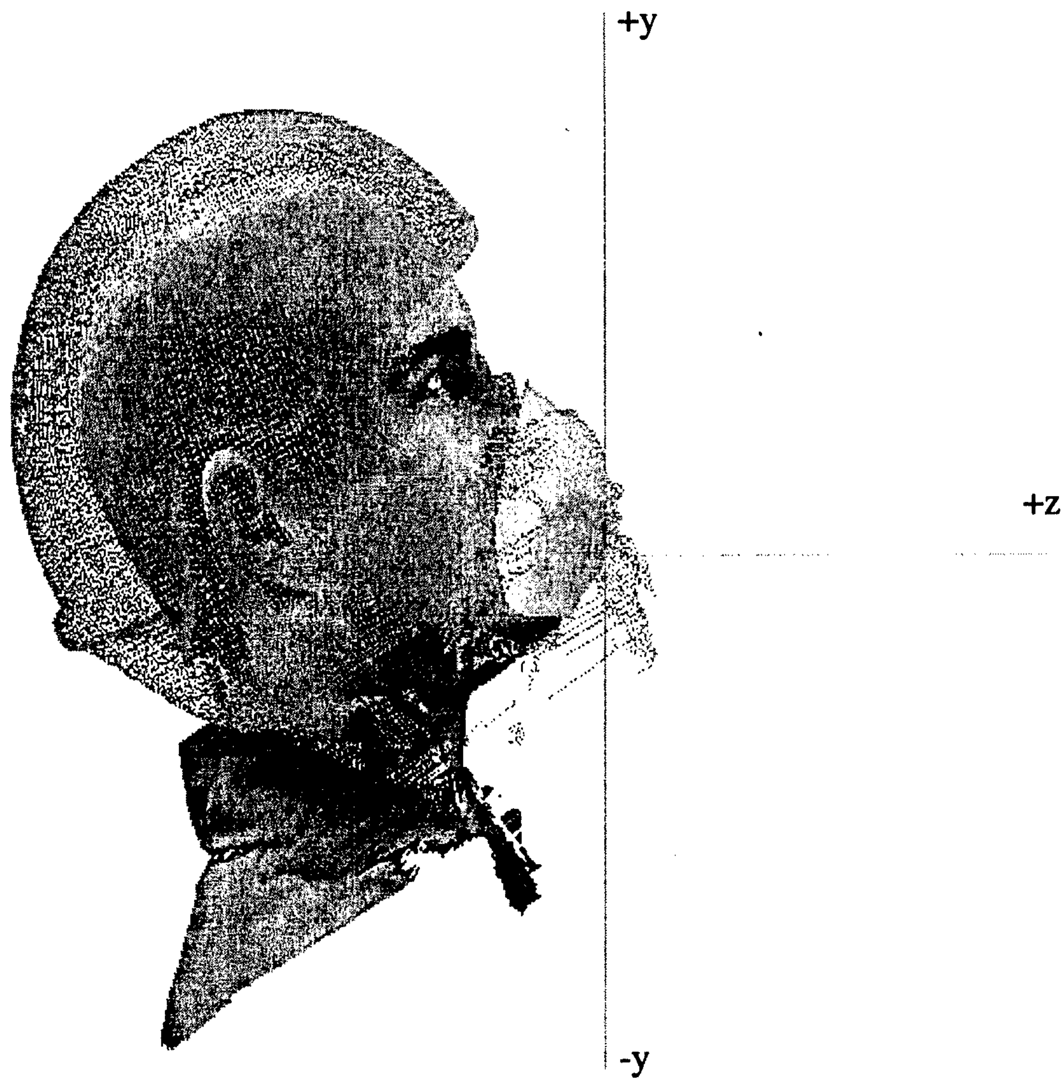


Figure 5. Unencumbered Subject Registered with Encumbered Subject and Mask

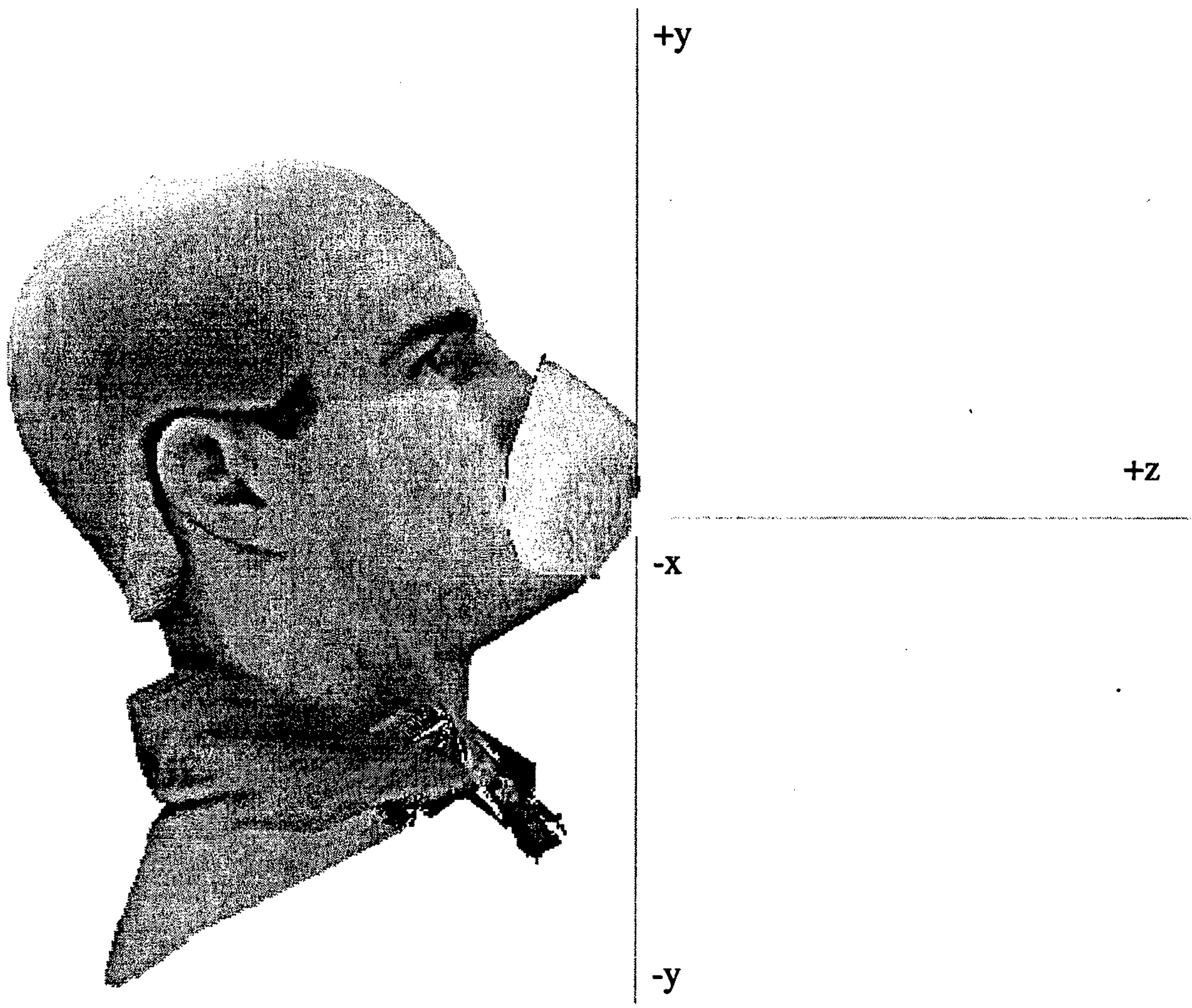


Figure 6. Unencumbered Subject Registered with Mask as Worn

The next step was to actually identify the data points on the face that contact the face piece to create the seal (the mask-to-face interface). Software was written to locate points on the face closest (within pre-defined angular constraints) to those points that define the outer edge of the mask face piece. All data points within three millimeters of the seal area's outer edge were then selected to represent the shape of the mask-to-face interface. These seal areas were visually checked for extraneous data points, and were subsequently edited if necessary. Finally, the three-dimensional coordinate locations of each of the points were written to an output file to be used in shape analysis. For a brief description of this software, see Appendix H.

SHAPE DESCRIPTION

Given the types of reported fitting problems, it was suggested that the traditional anthropometry may not provide enough information to determine why some subjects received good fits in the mask and others did not, and whether to adjust, reclassify, or add sizes. Rectangular coordinates from the 3-D scans collected in the field provide the shape information needed to fill in the knowledge gaps and to help make useful decisions. One method of describing shape involves utilizing the 3-D location of homologous anatomical landmarks. Another method is curvature analysis of the mask-to-face interface contour.

Distances Between Landmarks

There were fourteen points from the hard shells and sixteen anatomical landmarks which could be considered as homologous landmarks from subject to subject. Appendix I contains the list of these landmarks and a diagram showing their location. XYZ coordinates were obtained for each of the thirty points that were used. Distances between these points were converted to Euclidean distances using the Euclidean distance formula:

(1) $d(i,j) = \sqrt{\left(x_j - x_i\right)^2 + (y_j - y_i)^2 + (z_j - z_i)^2}$ which is the distance from the i^{th} point to the j^{th} point.

Curvature and Torsion

Curvature and torsion are two common measurements used to describe a curve. In this case, the curve is the contour of the mask-to-face interface. The motion of curvature around a curve can be illustrated by a hinge joint with movement in only one plane. The motion of torsion around a curve can be illustrated by a ball joint; its motion can move outside the plane. Formal mathematical definitions for curvature and torsion can be found in any textbook on vector calculus.

Curvature analysis refers to the computation of curvature and torsion. It begins with the parametric polynomial representation of the mask-to-face contour with respect to proportional arc length, s. One contour is represented by three polynomials: X(s), Y(s), and Z(s). These polynomials are then used to compute curvature and torsion at each point along the arc.

Some processing was necessary in order to get the data ready for curvature analysis. The contour is made up of 3-D points, but each point must be described in terms of arc length. The arc length between each successive point in the contour was estimated using the Euclidean distance formula. The proportional arc lengths were then computed at each point along the contour.

Two methods of computing the parametric polynomials were examined: regression and splines.

Regression analysis was used to compute cubic polynomial parametric equations for x, y, and z as a function of proportional arc length, s, in the mask axis system. Several attempts were made to find a good fit for one subject. First, 100% of the arc was examined. This resulted in one set of parametric equations to fit the entire data set. The parametric equations were then used to calculate predicted values of x, y, and z coordinates at s. Figures 7, 8, and 9 are bivariate plots of the x, y, z coordinates against s, respectively. The asterisks indicate the actual x, y, or z coordinate values at s and the P's indicate the predicted x, y, or z coordinate values at s. A good fit to the data would be indicated by a close alignment of the P's with the asterisks. It is clear that these parametric equations do not provide a good fit to the data.

The data for one subject were then examined for right/left symmetry by comparing the absolute mean values for x, y, and z on the right and left side of the arc (50% of the data on either side of the face). The absolute mean values as given in Table 1 do indicate right/left symmetry at least for that subject, so 50% of the data were used to compute parametric equations. However, this also resulted in a poor fit to the data.

TABLE 1

Comparison of Right and Left Absolute Mean Values
(data are in millimeters)

	X	Y	Z
Right	25.48	51.35	50.67
Left	23.67	51.92	50.01

Next, 30% of the data were used with no better fit to the data. Finally, the data were broken into segments of 0% to 15% and 15% to 30%. This gave two sets of parametric equations, one for each segment. Appendix J contains Figures J1 through J6, showing that these equations appeared to provide a good data fit for the subject. Figures J1, J2, and J3 are bivariate plots of actual and predicted data for 0% to 15% of the arc. Figures J4, J5, and J6 are bivariate plots of actual and predicted data for 15% to 30% of the arc. Curvatures and torsions were then computed using each set of parametric equations at points equally spaced along the arc. The results showed that the curvatures and torsions were non-continuous at the segment endpoints (i.e., the torsion for the first set of parametric equations ending at 15% had a positive sign, while the torsion for the second set of equations beginning at 15% had a negative sign). It was determined that the regression methodology did not allow the segment endpoints to connect, thereby causing the break in continuity in the curvature and torsion values.

Quintic splines are continuous at the first, second, and third derivatives, eliminating the discontinuity problem. The SAS/INSIGHT module (Statistical Analysis Software, 1995) provided the means to fit splines to data; however, it was unable to output the polynomials associated with the splines. L.S.A. (Nurre, 1995) was used to output the polynomials. The first task was to determine the number of control points (or the number of splines) to fit the data. An attempt was made to use SAS to determine these two parameters by reasoning that the degrees of freedom in SAS would be equal to the number of control points requested by L.S.A. As it turns out, this is not the case. Furthermore, there is no way to relate the SAS output to input for L.S.A., so SAS was abandoned. After experimenting in L.S.A. with the arc data sets for three subjects, the number of control points (100) and the smoothness parameter (the smallest available) were selected by visual inspection. A set of polynomials for each segment between control points was generated for each subject. Since there are 100 control points, there are 100 sets of polynomials per subject. The smallest smoothness parameter gave the smallest error in fit. Figures J7, J8, and J9 in Appendix J are snapshots of the screens generated by L.S.A. for one subject showing the spline fits of x, y, and z as a function of s, respectively. Figure J10 is a snapshot of the x, y, z spline fits viewed simultaneously; you can see the outline of the mask seal area as if you were looking at the subject. An advantage is that the actual data points and the line through them shows the spline fit. The same number of control points and the same smoothness parameter were applied to each subjects' data.

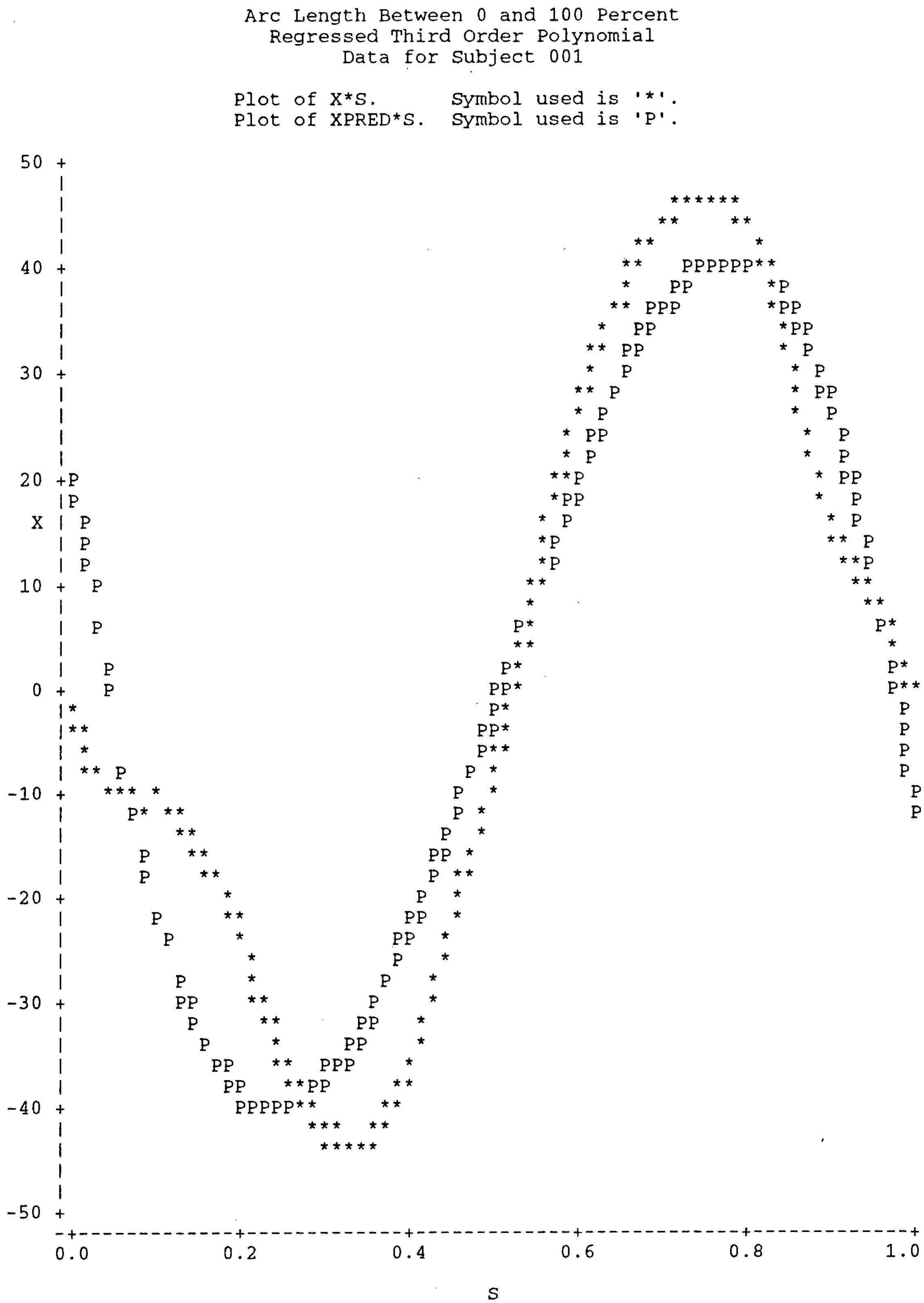


Figure 7. Arc Length Between 0 and 100 Percent for X With Respect To S

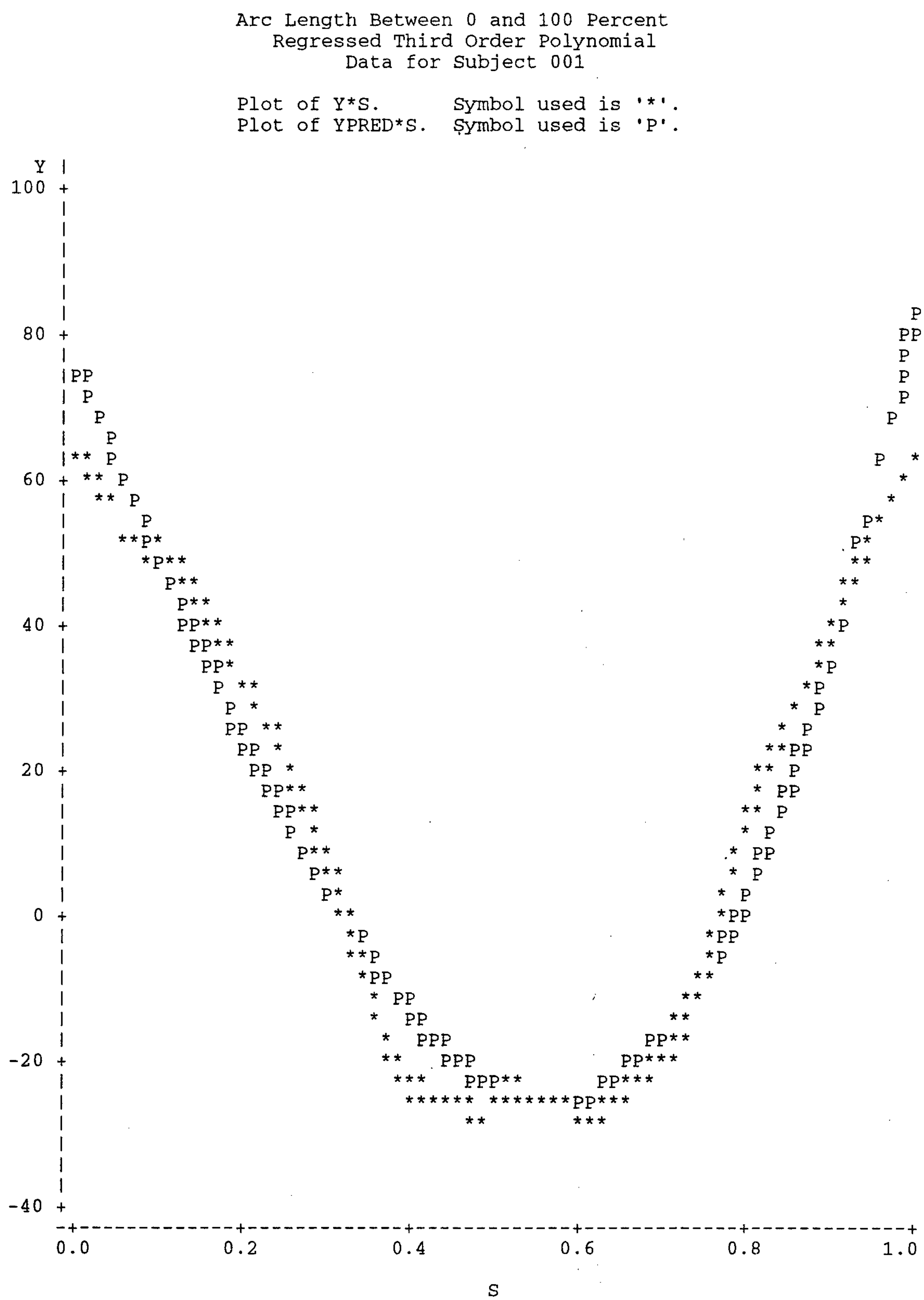


Figure 8. Arc Length Between 0 and 100 Percent for Y With Respect To S

Arc Length Between 0 and 100 Percent
Regressed Third Order Polynomial
Data for Subject 001

Plot of Z*S. Symbol used is '*'.
Plot of ZPRED*S. Symbol used is 'P'.

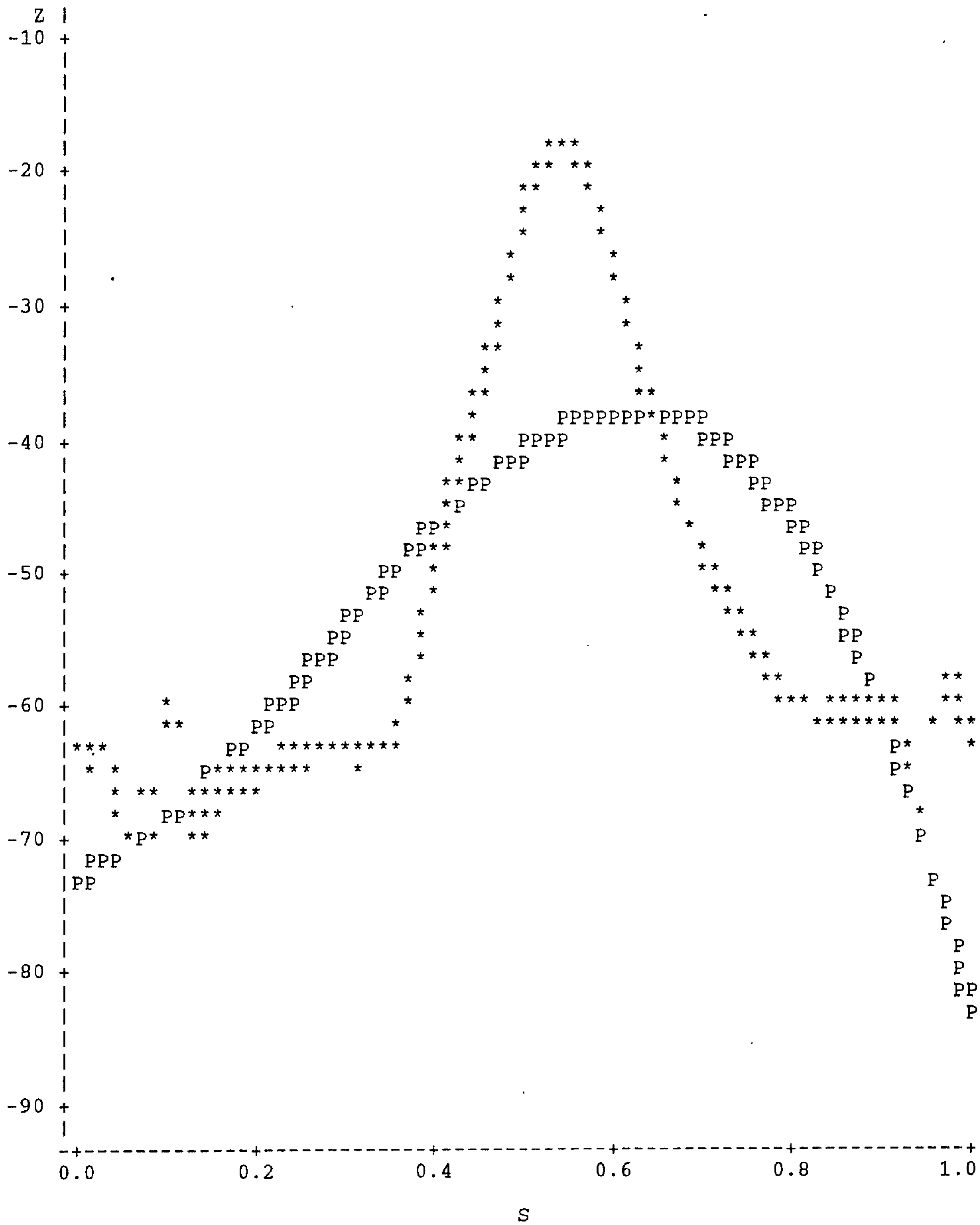


Figure 9. Arc Length Between 0 and 100 Percent for Z With Respect To S

The polynomials were then used to resample the data so that there would be the same number of points per subject (800) and to ensure that the proportional arc lengths were homologous between subjects. Finally, curvature and torsion were computed for each resampled point.

The polynomials were also used to compute critical points on the contour. Critical points are local minimums and maximums. They are found by computing the first derivatives at each successive point and comparing them to adjacent derivatives. If the derivative at the previous point, say k-1, is positive and at k+1 the derivative is negative, then there is a local maximum at point k. Similarly, there is a local minimum at point k if the derivative at k-1 is negative and the derivative at k+1 is positive.

The idea was to reduce the number of data points required for statistical analysis to just the number of critical points to be found. Figures J11 through J13, also in Appendix J, are bivariate plots of the critical points on x(s), y(s), and z(s) for one subject. Critical points are indicated by asterisks, showing that several critical points are found that may not be 'critical' to our analysis because of noise in the data, where they are located, etc. There is really no way to weed these points out. Furthermore, there was no way to combine the information from the three sets of polynomials to determine if a critical point was critical for more than one axis. Computed critical points, therefore, were abandoned.

DATA ANALYSIS

Four different statistical methods were used in this study: 1) Analysis of Variance (ANOVA) and Multivariate Analysis of Variance (MANOVA), 2) Principal Component Analysis (PCA), 3) Euclidean Distance Matrix Analysis (EDMA), and 4) Radial Difference Mapping (RDM). These analyses focused on variation in the 2-D and 3-D data caused by wearing different mask sizes, and on variation affecting overall score.

ANOVA/MANOVA

Analysis of Variance (ANOVA) and Multivariate Analysis of Variance (MANOVA) were conducted using all traditional anthropometric measurements. (An explanation of the need for a multivariate technique to examine this data and a description of MANOVA are given in Crist et al., 1995.) The analysis looked at the mean values of subjects grouped by mask size and overall score. The analyses were used to determine three things: 1) whether there are significant differences in measurements between subjects wearing different sizes; 2) whether there are significant differences in measurements between subjects with different overall scores; and 3) whether there are significant differences in subjects' measurements between passes and fails which are dependent on the mask size. For these analyses, alpha was set at .05 and Type IV sums of squares were used for testing.

Several statistical analyses were performed using 3-D data. The purpose of these analyses was to determine 1) differences in face shape between passing and failing subjects, 2) differences in face shape between subjects wearing different sizes, and 3) differences in the four mask sizes themselves.

PRINCIPAL COMPONENT ANALYSIS

Principal Component Analysis (PCA) (Mardia et al., 1979; Johnson and Wichern, 1988) was performed on the facial contours represented by curvature and torsion. PCA is a multivariate technique that seeks to find p principal components for a data set with p variables. Each principal component is a linear combination (with unit length) of the original variables. The coefficients of the principal components are the eigenvectors of the correlation matrix. The eigenvalues are equal to the variances of the components. In this application, the first and second principal components are of interest. The first component is the linear combination of p variables with the largest variance. The second component has the second largest variance and is perpendicular and not correlated to the first component. When the first two components provide a good fit to the data, they will explain a large percentage of the overall variance between subjects. Finally, the magnitude and direction of the coefficients of each component are examined. The coefficients of largest magnitude indicate the locations (represented by proportional arc length) on the contour that are most important in discriminating between subjects.. The direction of the coefficients indicates the relationship of the coefficients to one another. For instance, all positive coefficients would indicate a general increase in curvature and/or torsion. A mixture of positive and negative coefficients would indicate that some locations on the contour significantly increase in curvature and/or torsion while others significantly decrease.

The unique feature of this PCA is that the actual contours of the four masks were included in the analysis. Plots of the data against the first two components were generated. It was thought that the subjects would cluster around the mask representing the size they wore, and that within those clusters, a pattern in the distribution of passes and fails might emerge. These results could then be traced back to the original data to indicate anthropometric differences between passing and failing subjects.

Notably, PCA for the entire data set (800 curvatures and 800 torsions per subject) required more computer memory than was available. Therefore, 30% of the data (240 curvatures and 240 torsions per subject) starting at the apex of the nose were analyzed. Again, the assumption of right/left facial symmetry is required for this analysis.

EUCLIDEAN DISTANCE MATRIX ANALYSIS

Euclidean Distance Matrix Analysis (EDMA) is a coordinate-free approach to shape comparisons using homologous landmark data. (For a detailed description of EDMA, see Lele, 1991, and Lele and Richtsmeier, 1991.) The XYZ coordinates of numbered landmarks were used for the EDMA. The Euclidean Distance Matrix (EDM) for these landmarks is then the matrix where the (i,j) entry is simply d(i,j) as given by the Euclidean distance formula (See Figure 10). Thus, if one was interested in the distance from the third landmark to the fifteenth landmark, the (3,15) entry in the EDM would be the answer.

$$\mathrm{EDM} = \begin{bmatrix} d(1,1) & d(1,2) & d(1,3) & \dots & d(1,30) \\ d(2,1) & d(2,2) & d(2,3) & \dots & d(2,30) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ d(30,1) & d(30,2) & d(30,3) & \dots & d(30,30) \end{bmatrix}$$

Figure 10. Euclidean Distance Matrix

Since the distance from the i^{th} landmark to the j^{th} landmark is the same as the distance from the j^{th} landmark to the i^{th} landmark, this is a symmetric matrix with zeros on the diagonal. This can easily be seen in Figure 10.

The Form Difference Matrix (FDM) denoted by D(X,Y) is computed by taking the ratio, element by element, from one EDM (F(X)) to another EDM (F(Y)). The (i,j) element of the FDM is the (i,j) element of F(X) divided by the (i,j) element of F(Y). The formula for the FDM is: $D(X,Y) = \frac{F_{i,j}(X)}{F_{i,j}(Y)}$ where 0/0=0. Since D(X,Y) is a symmetric matrix with zero diagonal, only the upper diagonal part is necessary to study the form difference. The elements of the FDM are the percentage change in the distances between landmarks used. Interpretation of these changes depends on the application. Any ratio smaller than 1 indicates the distance in F(Y) between the i^{th} and j^{th} landmarks is larger than the distance in F(X).

Similarly, any ratio larger than 1 indicates the distance in F(Y) is smaller than the distance in F(X). The ratios from these FDMs which are "substantially larger or substantially smaller than 1" (Lele and Richtsmeier, 1991) are then the ratios of interest which denote the areas of the greatest amount of change. As with the interpretation of the changes, the interpretation of "substantial" is also application dependent.

Each subject in this study has an associated EDM. EDMs of subjects who wore the same size and had the same type of fit are then averaged together by gender to obtain one EDM for each category of fit within a size by gender. For example, all men who wore an SN mask and received a good fit were averaged into one EDM. The differences of interest are between the subjects who received a good fit and those who received a poor fit. Consider the EDM for males in a size SN who received a good fit (call it F(X)) and the EDM for males in a size SN who received a poor fit (F(Y)). The FDM is D(X,Y) given by the formula above. Thus, the FDM looks at the differences within the SN size between the men who received a good fit and the men who received a poor fit. In looking for ratios substantially larger or substantially smaller than 1, the changes of interest were restricted to those greater than 20%, i.e. ratios smaller than .80000 and greater than 1.25000.

RADIAL DIFFERENCE MAPPING

Radial difference mapping is a process that compares radial distances from a data point on one object to its counterpart on a different object (Whitestone, 1994). The output provides both a visual, in the form of a topographical-type map, and quantitative description of the radial differences between two or more objects. It was hoped that, by observing radial difference maps (RDMs) of the faces of subjects that received good fits in a mask versus those that received poor fits, clues to critical facial shape differences would become more obvious. To explore this possibility, RDMs for three subjects that received a good fit in the MN mask were compared to three subjects that received poor fits in the same size. All subjects' faces were compared to a benchmark subject, who, based upon fit scores, received the best overall fit in the MN mask (Figure 11).

Colors were selected to represent different three-millimeter intervals (e.g., dark green represents all data points on one object zero to three millimeters farther away from the reference object, blue represents all data points on one object three to six millimeters away, etc.). See Table 2 for the complete RDM key. Of the six subjects examined, no obvious patterns in the RDMs stood out as discriminating evidence of fit differences; therefore, radial difference mapping was not continued on a larger scale.

TABLE 2.

Key for Radial Difference Mapping

RADIAL DIFFERENCE MAP KEY	
COLOR	DISTANCE FROM REFERENCE OBJECT
Violet	> 9 mm
Indigo	6-9 mm
Blue	3-6 mm
Dark Green	0-3 mm
Bright Green	0 - (-3) mm
Yellow	-3 - (-6) mm
Orange	-6 - (-9) mm
Red	< -9 mm

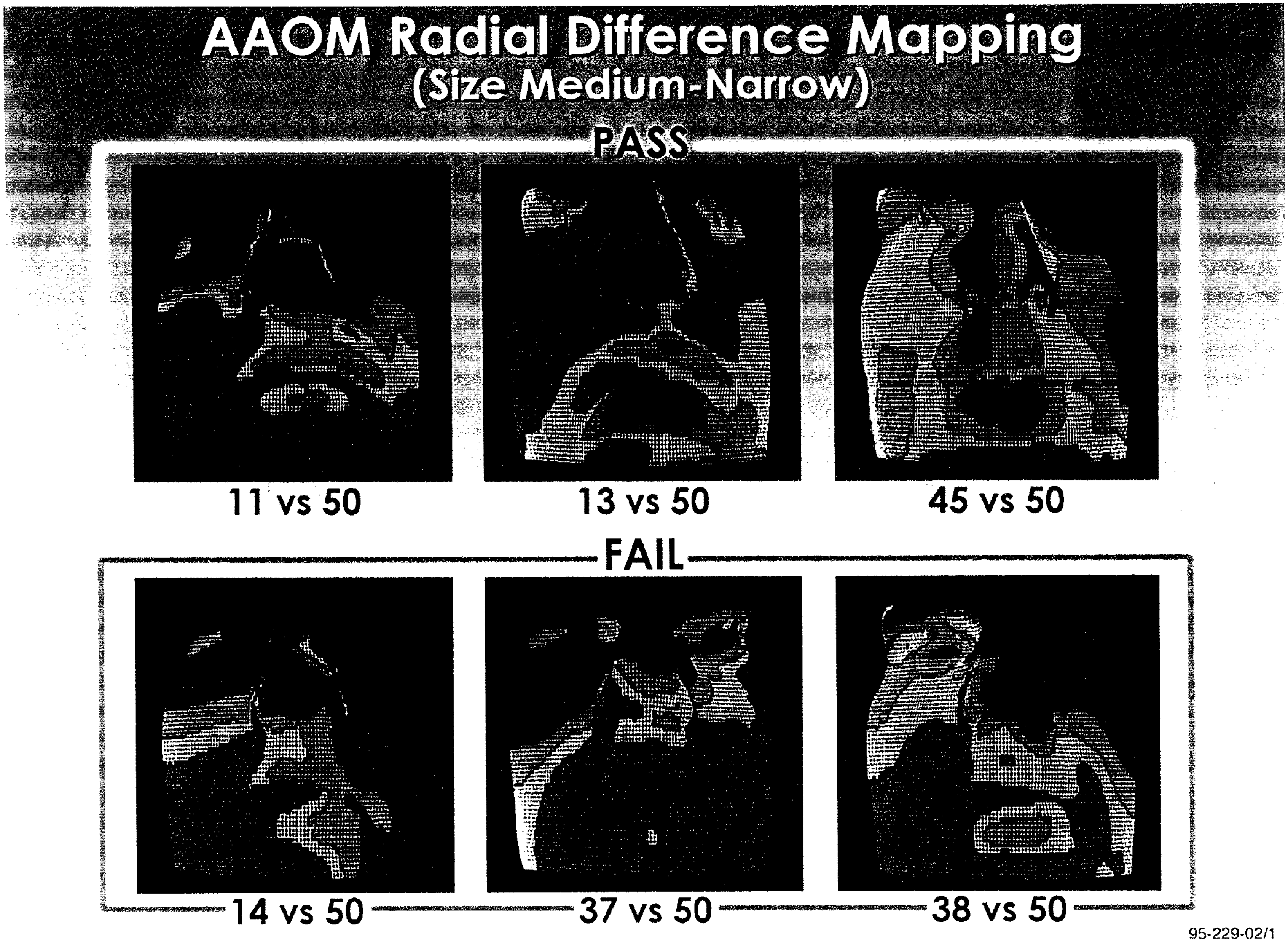


Figure 11. AAOM Radial Difference Maps

RESULTS

SUMMARY STATISTICS

Thirty male and 30 female subjects were tested. Appendix K contains tables of summary statistics for the subjects. Tables K1 through K5 show the frequency distributions for demographic data. Most of the subjects were white. There was a broad distribution of ages for males, but a large percentage of females were 22 and 23 years old. This is explained by the fairly recent entry of females into the pilot program. Tables K6 and K7 contain summary statistics for their traditional anthropometry.

Table 3 shows the frequency of subjects by mask size.

TABLE 3

FREQUENCY OF MALES AND FEMALES BY MASK SIZE

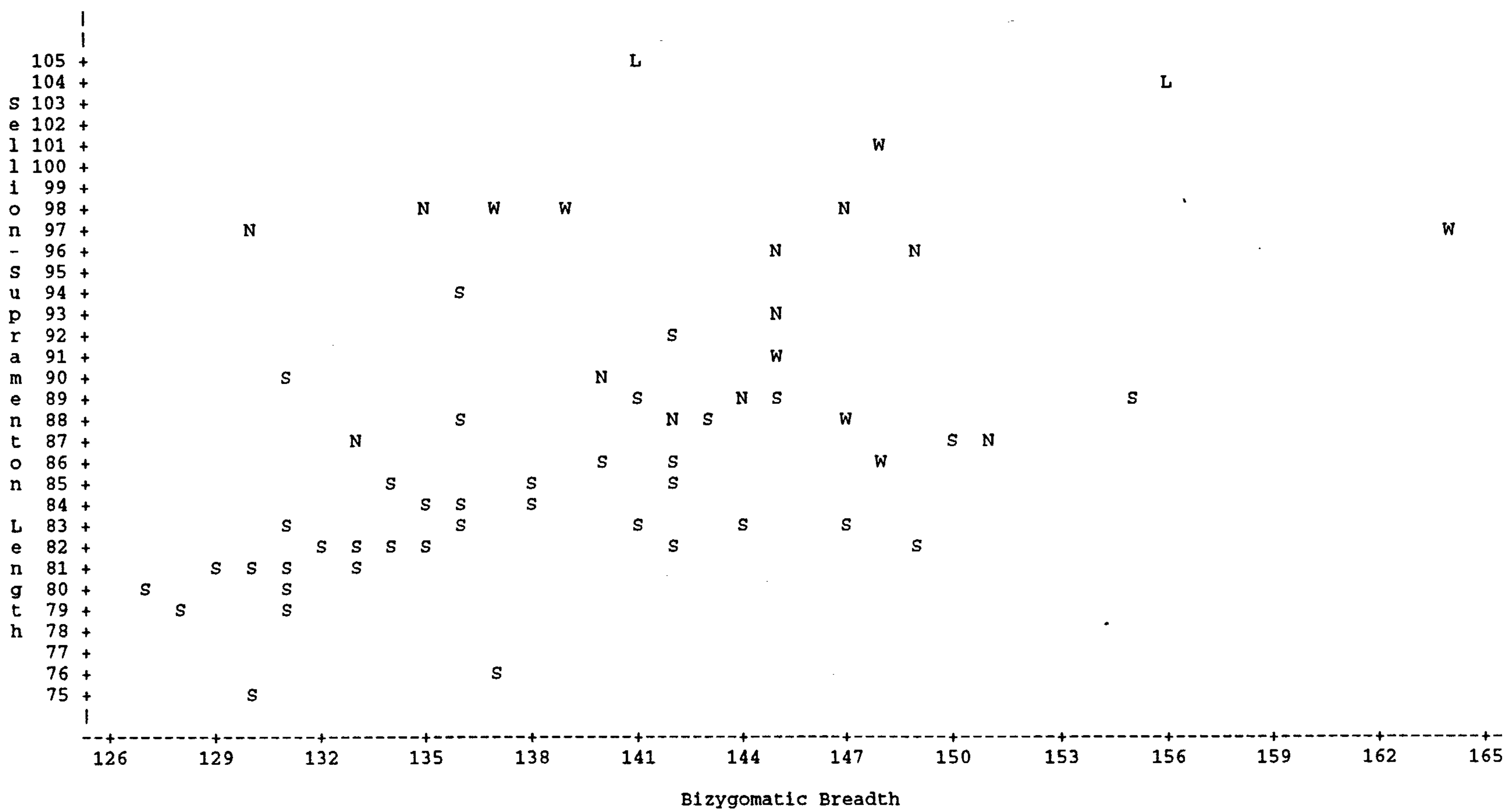
		Mask Size				
		LW	MW	MN	SN	TOTAL
Sex	Male	2	7	10	11	30
	Female	0	1	0	29	30
	Total	2	8	10	40	60

Figures 12 and 13 show the distribution of subjects by mask size (based on Sellion-Supramenton Length and Bizygomatic Breadth) and sex.

Male and female subjects were grouped into "pass/fail" categories based on the leakage, comfort, and slippage fit test ratings felt to be most relevant and reliable. Area leakage and comfort ratings and overall slippage ratings were measured on a scale from 1 to 4 where 3 (moderate problems) and 4 (excessive problems) are considered fails. Overall leakage ratings are measured on a scale from 1 to 5 where 4 (fair) and 5 (poor) are fails. Overall comfort ratings are also measured on a scale from 1 to 5; however, 3 (moderately uncomfortable), 4 (very uncomfortable), and 5 (hot spots) are considered fails. A subject who failed on any one of the area leakage or comfort ratings failed overall. A subject who failed only on slippage did not fail overall, because slippage is not considered as critical to fit as the other ratings. Examining who failed what and where could help us design a better fitting mask.

Distribution of AAOM Subjects
For Mask Size: S=SN, N=MN, W=MW, L=LW
Data are in MM

Plot of X7*X5. Symbol is value of MASK.

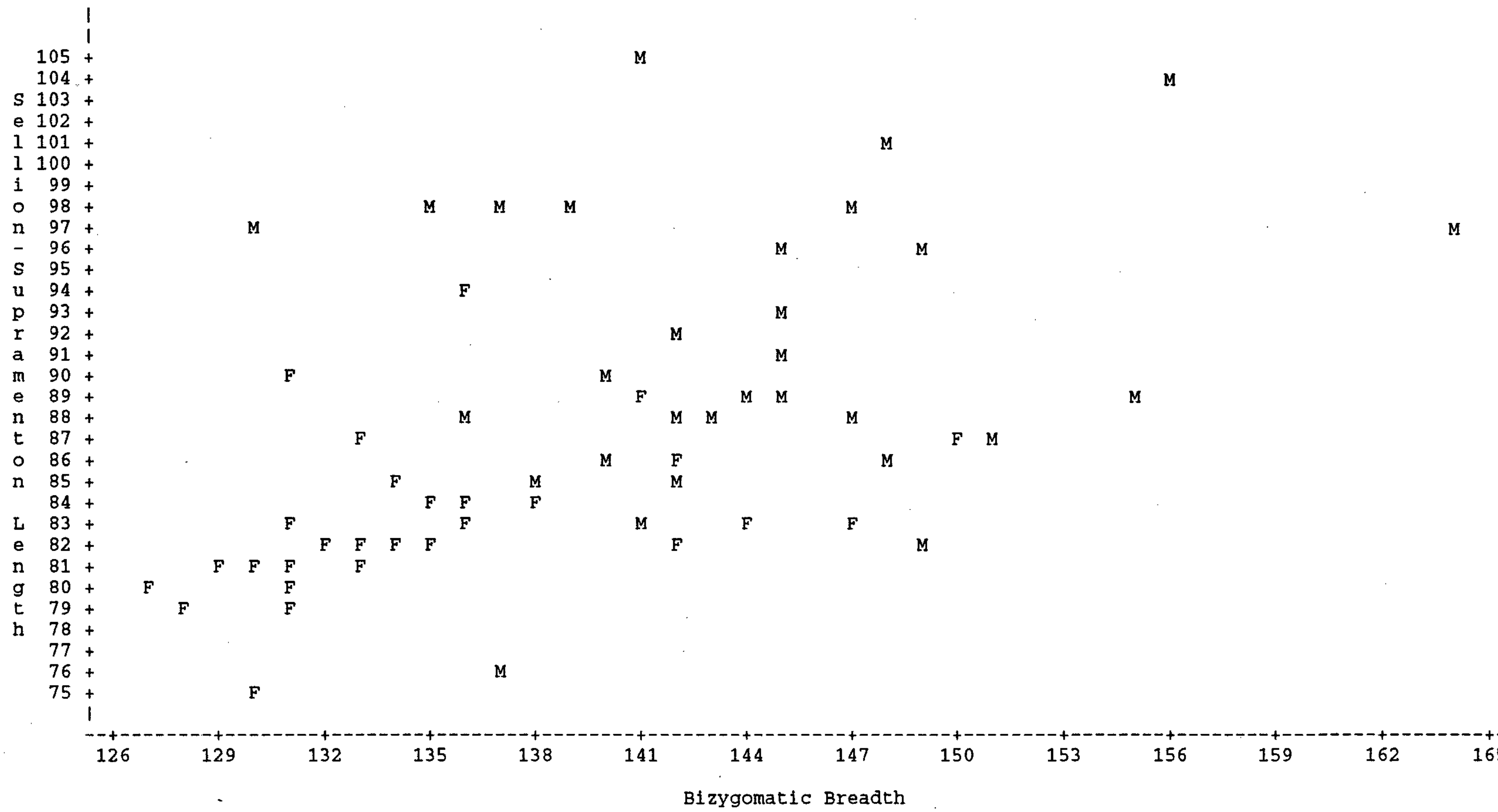


Two subjects hidden due to overlap of data points.

Figure 12. Distribution of AAOM Subjects by Mask Size

Distribution of AAOM Subjects
For Sellion-Supramenton and Bizygomatic Breadth
Data are in MM

Plot of X7*X5. Symbol is value of SEX.



Two subjects hidden due to overlap of data points.

Figure 13. Distribution of AAOM Subjects by Sex

Tables 4 and 5 show the frequency of pass/fails and the frequency of failure causes.

TABLE 4

FREQUENCY OF PASS/FAILS BY MASK SIZE (MALES)				
		Overall Score		
		Overall Fail	Overall Pass	Total
Mask Size	LW	1	1	2
	MW	4	3	7
	MN	5	5	10
	SN	4	7	11
	Total	14	16	30

TABLE 5

FREQUENCY OF FAILS BY SIZE AND FAILURE TYPE (MALES)								
		Fail Category (L=Leaks, C=Comfort, S=Slips)						
		L	C	L and C	L and S	C and S	L, C, and S	Total
Mask Size	LW	0	0	0	0	0	1	1
	MW	1	2	1	0	0	0	4
	MN	2	2	0	0	0	1	5
	SN	1	3	0	0	0	0	4
	Total	4	7	1	0	0	2	14

Of the 29 females in size SN, there were 4 failures. Three of those failures were due to discomfort. One failure was due to a leak in the chin area. One female wearing size MN failed due to slippage and to a leak on the left side of the nose.

Ideally, all 60 subjects would have had PPG experience at a minimum of 9 G. Subjects with both PPG and high-G experience were rare, however, particularly among females. Twenty-six males and two females had some combination of the desired experience. Twenty males had sorties in a fighter: 16 to 9G (one without PPG) and 4 to 7G (two without PPG). Six males had experience with centrifuge rides to 9G. Two females had experience with centrifuge rides to 9G. Tables 6 and 7 show the effect of PPG experience on overall score. Subjects who have no PPG experience tend to pass more often than fail. This is especially true with the females who have little or no experience.

TABLE 6

Frequency of Male Overall Scores By PPG Experience

	Fail	Pass	Total
No PPG	3 10%	4 13.3%	7 23.3%
Yes PPG	11 36.7%	12 40%	23 76.7%
Total	14 46.7%	16 53.3%	30 100%

TABLE 7

Frequency of Female Overall Scores By PPG Experience

	Fail	Pass	Total
No PPG	4 13.3%	24 80%	28 93.3%
Yes PPG	1 3.3%	1 3.3%	2 6.7%
Total	5 16.7%	25 83.3%	30 100%

The measurement for Sellion-Supramenton was compared to the T.O. criteria for assigning mask size based on Sellion-Supramenton (SN: less than 87mm, MN and MW: 87 to 100 mm, LW: greater than 100 mm). Of the 30 male subjects, seven (23.3%) were tested in sizes other than their T.O. size. They are shown in Table 8.

TABLE 8

Frequency of Subjects Not Tested in T.O. Size

TESTED SIZE	T.O. SIZE	OVERALL SCORE	FREQUENCY
MW	SN	PASS	1
MW	LW	FAIL	1
SN	M	PASS	4
SN	M	FAIL	1

The female data is considered suspect for several reasons. Twenty-nine out of 30 female subjects wore size SN with few fails. The female data should have about the same range of variation in faces as males, and therefore, would not be expected to fit into one size, let along fit well into that size. For passing males in size SN, Bizygomatic Breadth ranges from 13.6 to 15.5 cm and Sellion-Supramenton Length ranges from 7.6 to 9.2 cm. The ranges for passing females are from 13 to 14.7 cm and from 7.5 to 8.5 cm, respectively. The ranges are similar enough that you would expect females to have a similar failure rate to males. Furthermore, few, if any, of these subjects had PPG experience, so they would not know how the fit on the ground might affect the fit at high g.

One method of fit testing is to test just one size on a random sample from the target population. The result is the quantification of the range of anthropometry where an acceptable fit in that one size is achieved and the development of a size that can be scaled up or down to generate more sizes to accommodate the expected range of variablility in the population. In this study, most all the females passed in one size. Based on that alone, one might conclude that there is no problem with the fit for these women and only one size is needed. However, we suspect that truly is not the case based on the failure rate observed in the males of similar anthropometry.

In an attempt to obtain a better distribution of passes and fails, we reevaluated the male and female data using stricter fail criteria. Slippage is ignored as a criterion. Fails for leakage and comfort in specific facial areas are 3 (slight problems), 4 (moderate problems), and 5 (excessive problems). Fails for overall leakage are 3 (OK), 4 (Fair), and 5 (Poor) and fails for overall comfort are 2 (slightly uncomfortable), 3 (moderately uncomfortable), 4 (very uncomfortable), and 5 (hot spots). The frequency of passes and fails in each size are shown in Tables 9 and 10. With the stricter criteria, nearly 87% of the males and 70% of the females are now considered fails; the proportions of both genders are skewed toward fails. These criteria obviously do not more evenly split the passes from the fails.

TABLE 9

AAOM MALE DATA REEVALUATED

TABLE OF OVERALL SCORE BY MASKSIZE

OVERSCOR MASKSIZE(Mask Size)

Frequency Percent Row Pct Col Pct	LW	MN	MW	SN	Total
FAIL	2 6.67 7.69 100.00	10 33.33 38.46 100.00	5 16.67 19.23 71.43	9 30.00 34.62 81.82	26 86.67
PASS	0 0.00 0.00 0.00	0 0.00 0.00 0.00	2 6.67 50.00 28.57	2 6.67 50.00 18.18	4 13.33
Total	2 6.67	10 33.33	7 23.33	11 36.67	30 100.00

TABLE 10

AAOM FEMALE DATA REEVALUATED

TABLE OF OVERALL SCORE BY MASKSIZE

OVERSCOR / Frequency / Percent / Row Pct / Col Pct	MASKSIZE(Mask Size) MN	SN	Total
FAIL	1 3.33 4.76 100.00	20 66.67 95.24 68.97	21 70.00
PASS	0 0.00 0.00 0.00	9 30.00 100.00 31.03	9 30.00
Total	1 3.33	29 96.67	30 100.00

It was originally suggested that we just reevaluate the females with this criteria. We feel strongly that it would be wrong to evaluate the genders differently. It would be poor experimental and scientific practice to treat one group differently than the other to achieve the desired results. We consider the male data reliable, so we do not want to redefine the pass/fail criteria for males or females. As the female data do not contribute to the understanding of what size constitutes a good fit, the male data will be used exclusively in all further statistical analyses, and it will be assumed that any conclusions regarding the male data will be valid for females as well.

VARIATION DUE TO MASK SIZE

An important step in the analysis was to determine exactly how the four mask sizes differ in shape. Three areas of the masks were identified that were thought to be critical to its shape. They are the face length, face breadth, and nasal root breadth. Visual inspection of the masks showed that:

- MN and MW are the same in face length. SN is the shortest of the masks, and LW is the longest of the masks.
- SN and MN are virtually the same in face width. MW is only slightly wider than MN. LW is obviously much wider than the other masks.
- MW appeared the narrowest in the area of the nasal root. Generally, no differences were found between LW, MN, and SN. It is suspected that the difference in MW is not important.

Plots of frontal views, x and y coordinates (Figure 14) of the four masks bear out these observations, as does MANOVA. Euclidean Distance Matrix Analysis was used to quantify these differences.

EDMA was able to quantify the differences between the sizes by looking at the distances between the landmarks on the masks. Only the distances involving the landmarks on the perimeter of the masks were looked at since it was thought that these should be the ones that matter in the fitting process. Face length was measured from the points TOP-MID MASK to BOTTOM-MID MASK. Face width was measured at the widest points, MAX LEFT to MAX RIGHT. See description in Appendix E and mask picture in Appendix I for location of points.

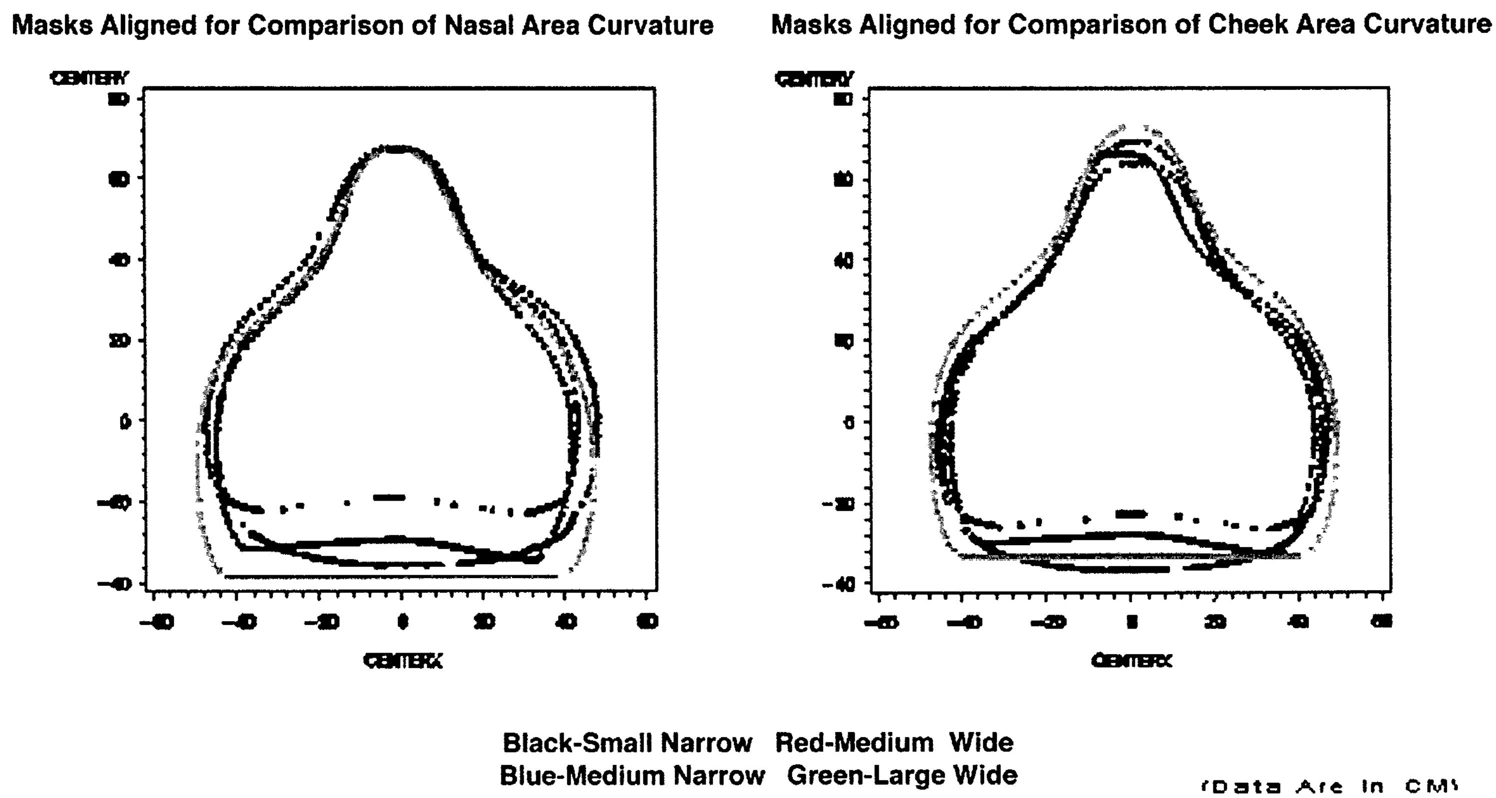


Figure 14. Comparison of the Four Mask Sizes

EDMA showed that, indeed, SN is the shortest mask in face length with SN 95% as long as MN, 94% as long as MW and 83% as long as LW. Also, LW is the longest in face length by 17% longer than SN, 13% longer than MN and 12% longer than MW.

SN and MN are almost identical in face width with SN .2% wider than MN. Thus SN and MN are the narrowest at 96.5% of the MW width and 90% of the LW width. LW is the widest of all masks and is 10% wider than SN and MN and 6.5% wider than MW.

EDMA only had one landmark in the nasal root area and thus could not verify the visual comparison at that point. However, EDMA was able to determine that there was one other difference of interest. Namely, the location of the minimum points MIN RIGHT and MIN LEFT which occur almost 10 mm closer to TOP-MID MASK for the MN size than for all other sizes. This is a difference of approximately 30%. A complete description of the changes found are contained in Appendix L.

Given that there are some physical differences in the four mask sizes, anthropometric differences between subjects wearing those masks would be expected. MANOVA (Appendix M) shows that at alpha=.05, there are no significant multivariate effects on anthropometry due to mask size (Wilk's Lambda p=.3913 and Pillai's Trace p=.4348). This indicates that the mean vectors for anthropometry do not differ depending on mask size.

Univariately (Appendix N), mask size is significant for Menton-Sellion Length (p=.0013), Sellion-Supramenton Length (p=.0001), Menton-Subnasale Length (p=.0256), and Nose Length (p=.0031). This is not a surprising result given that Sellion-Supramenton Length is the measurement used in the T.O. sizing criteria, and the lengths of the rest of the mask were probably scaled based on that variable.

Tukey's multiple pairwise comparisons of size means (Appendix N) at alpha=.05 show that: 1) for Menton-Sellion Length, subjects wearing size SN are significantly smaller from subjects wearing the other three sizes; 2) for Sellion-Supramenton, subjects wearing size SN are significantly smaller than the subjects wearing the other three sizes, and subjects wearing size LW are significantly larger than those wearing the other sizes; 3) for Menton-Subnasale and Nose Length, subjects wearing size SN and LW are significantly different from each other, but not from those wearing the other sizes. As expected, subjects wearing sizes MN and MW are not significantly different in Sellion-Supramenton Lengths with means of 123.3 for MW and 121.3 for MN.

Given that there are no T.O. criteria for assigning width sizes, the size selection process may have prevented us from detecting differences in anthropometry between sizes MN and MW. It is entirely possible that sizes MN and MW are essentially the same. Five male subjects were retested. Three of them were tested in both sizes. Two were just tested in the medium size other than the one in which they were initially tested; for example, if the subject was tested in size MN during the survey, they were retested in size MW. The data are given in Appendix O and are inconclusive. It should be noted that all three of the subjects that were retested in a size changed overall score. This point will be discussed later.

Overall, the EDMA found few significant differences between subjects grouped by mask size. For a distance to be significantly different from one size to another, the percentage of change was required to be greater than 20%. Due to this requirement, the Sellion-Supramenton Lengths between sizes were just barely insignificant. If the percentage of change was lowered to approximately 16%, Sellion-Supramenton Length becomes significant. EDMA comparisons were only made between subjects who received good fits. The subjects who failed to get a good fit were not included in this analysis since it was thought that they might not truly be in the size in which they failed. (For example, a fail in SN possibly should have been in an MN.) Thus they might throw off the comparison. (ANOVA/MANOVA performed to look at the interactions is similar to this. The results are described below.) Detailed results appear in Appendix P.

VARIATION AFFECTING OVERALL SCORE ACROSS AND WITHIN SIZES

MANOVA (Appendix M) shows that overall score (Wilks' Lambda p=.1408 and Pillai's Trace p=.1408) or the interaction between mask size and overall score (Wilks' Lambda p=.2901 and Pillai's Trace p=.3600) are insignificant.

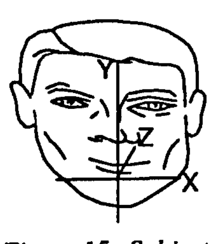
Univariately (Appendix N), overall score is significant for Head Breadth (p=.0120) and marginally significant for Bizygomatic Breadth (p=.0533). However, Tukey's multiple pairwise comparisons of mean Head Breadth and Bizygomatic Breadth between the two groups does not indicate a true significant difference at alpha=.05.

Since helmet size is determined by Head Breadth, the above result seemed to indicate that there may be some correlation between helmet size and overall score. The expert fitters at Brooks agreed that helmet size might be a factor. Twenty-seven subjects wore helmet size L. Of those, 13 passed and 14 failed. Only three subjects wore helmet size XL and all of them passed. An ANOVA (Appendix P) was conducted to examine the effect of overall score on Head Breadth for subjects wearing helmet size L. Subjects wearing helmet size XL were excluded from the analysis since none of them failed. Overall score was not significant at alpha=.05 (p=.0990). Therefore, this study provides no data to support the notion that helmet size affects fit.

Principal Component Analysis (PCA) of curvature and torsion data (Appendix Q) did not discriminate among subjects any better. The first component explained only 11% of the variation between subjects and the second component explained only 7% of the variation between subjects. Therefore, a total of 17% of the variation between subjects was explained by curvature and torsion. As expected based on this result, a plot of the first and second components did not show any pattern in the distribution of mask sizes or overall scores.

The EDMA showed that there were no significant anthropometric differences between passes and fails for subjects within a size. Interestingly, it did show that the areas of change between passes and fails within a size which were significant were non-anthropometric differences. These are all mask placement issues. Detailed results are given in Appendix R.

The two areas which the EDMA consistently showed to be the most significant areas of difference were placement of the mask top center point relative to the midpoint of the nose and placement of the bottom center point of the mask relative to promenton. These two distances were plotted against each other to look for a pattern of how the mask placement affected passes and fails. The plots of these 3-D distances showed a lot of variability in the data. Also, a band where there were no data around the zero point was noticeable. (The zero point indicates colocation with either the sellion or promenton landmark.) This gap was due to the thickness of the hard shell and face piece. Since the distance from the midpoint of the nose to the mask top center point is extremely difficult to measure, the distance from the mask top center point to sellion is being used as a reference for mask placement.



The scans of the subjects were aligned in an axis system where the Z-axis was the projection back into the head of the subject. (See Figure 15 at left.) To determine a practical method for proper mask placement, it was necessary to look at the data in 2-D. Since the largest amount of variability was due to the Z direction, only the XY coordinates were used. Only the areas which 3-D analysis had determined to be significant were looked at in the 2-D analysis.

Figure 15. Subject Alignment

RECOMMENDATIONS

Figure 16 illustrates the distance from the mask edges to sellion and promenton as well as the fit obtained by each of the men. Subjects who wear the mask such that the top of the mask is between 9 mm below sellion to 4 mm above sellion while the bottom of the mask is between 5 mm below promenton to 13 mm above promenton receive a poor fit. Thus wearing the mask in both of these areas simultaneously should be avoided. It is suspected that the underlying structure of the nose in that particular area around sellion is too bony to allow sufficient tissue deformation for a good seal. Additionally, when the bottom of the mask is in the area mentioned around promenton, it protrudes off the face. It is probable that this moves the mask off the face enough to make the lack of tissue deformation in the nose region noticeable. This lack of contact with the face probably causes an improper seal which leads to a poor fit. The 2-D analysis of the fit data simply confirms the fit area that is described in T.O. 14P3-1-161 is the proper placement for the MBU-20/P mask.

Creating New Mask Sizes

There were anecdotal recommendations from expert fitters for Small Wide (SW) and Large Narrow (LN) sizes. Due to lack of sample data for some segments of the female population, there is a possibility of an Extra Small Narrow (XSN) size being needed. No anthropometric reasons were found for these new sizes other than the fact that the sample was void of subjects with small faces. It is not unrealistic to expect that these women exist and that they will need a smaller size. If we assume that the anthropometric data for the females are reliable--that size SN fits them well--we can simply scale it down to create a smaller size. Size LN can be generated by scaling up size MN, and size LW can be generated by scaling up size MW. The following size descriptions are simply estimations.

An attempt was made to use the 3-D digitized pictures of the four current sizes for scaling purposes. We were able to obtain the XYZ coordinates of the landmarks on the hard shell of the masks. Most of these points are critical or inflection points which will help define the shape of the hard shell. The masks were placed into a common axis system defined by Bottom Midpoint of the Mask as the origin and Top Midpoint of the Mask as a point on the Y-axis and Minimum Left as an off axis but coplanar point defining the XY-plane. The masks were centered such that the landmarks were symmetric about the Y-axis. The XYZ coordinates of the referenced landmarks were then obtained for each hard shell of the current sizes.

Simple proportional growth of each landmark was computed for the new mask sizes. Landmark coordinates for LN were computed by taking the growth between SN and MN and applying it to size MN. This same growth (or shrinkage) was applied to SN to obtain the coordinates for the XSN size. For size SW, the growth between LW and MW was applied to size MW. This yielded the XYZ coordinates which can be used with the Fused Deposition Modeler® at Brooks AFB, Texas. These coordinates are provided in Appendix S.

Figure 17 shows the landmark locations in the XY plane for sizes MN, SN, and the new XSN. Size XSN is a distorted, unrealistic version of the mask. While it is shorter than sizes SN and MN, the curve around the nasal area is noticeably larger. The reason for this is that the relationship between sizes SN and MN is disproportional, as can be seen in the figure. Size SN is larger than MN around the nasal curve. That relationship was transferred to sizes SN and XSN so that the nasal curve of size XSN is larger than the curve of size SN and even larger than that of size MN. Clearly, this method of scaling works best when the relationship between the two sizes used for scaling purposes is appropriate. One way to avoid this problem may be to check the direction of the relationship for each set of landmark coordinates. In the case where SN is larger than MN in any direction, reverse the direction of the change to generate size XSN. Of course, this methodology has not been applied in practice. We recommend that the method be validated by creating and testing prototypes.

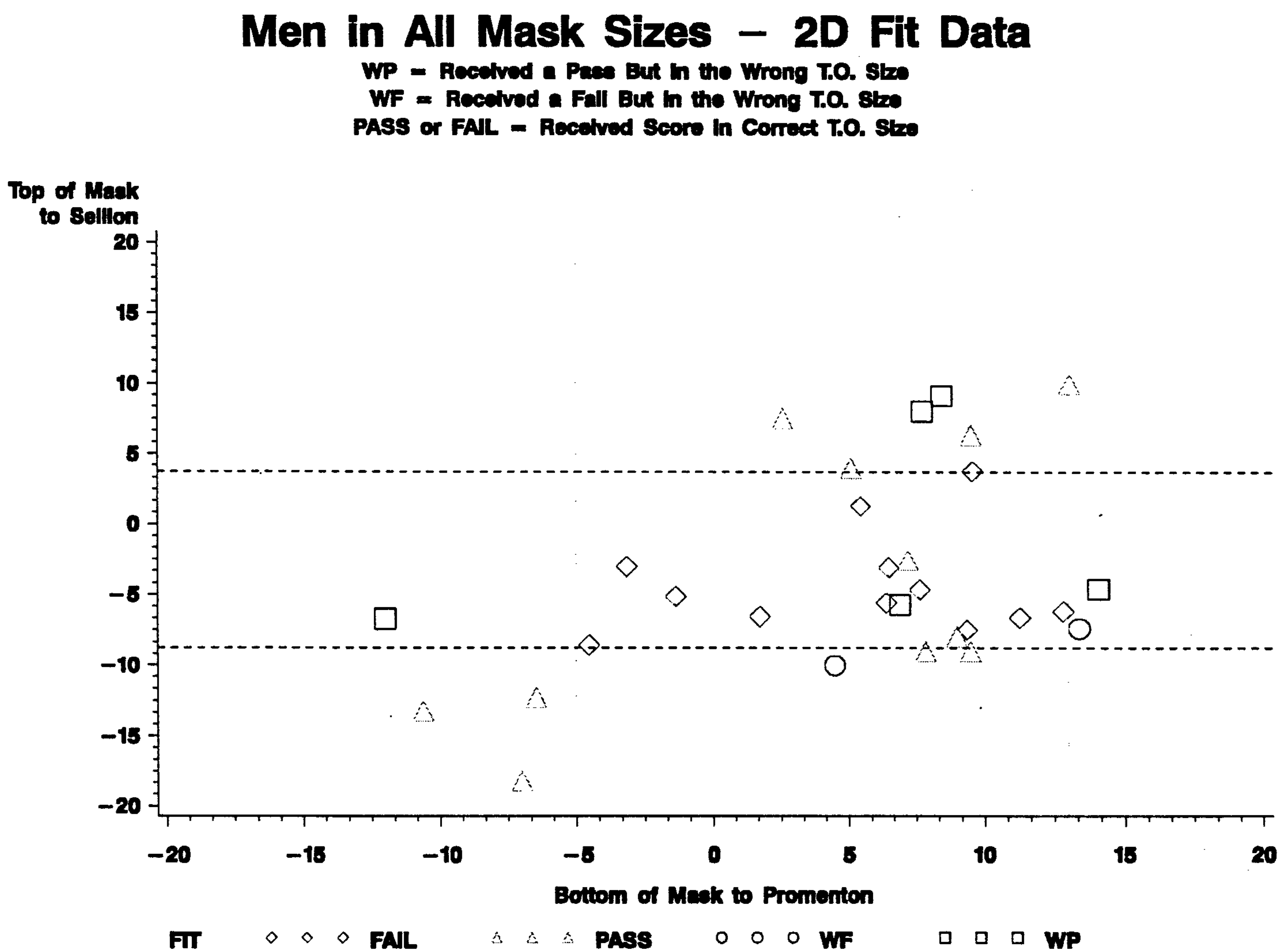


Figure 16. Men in all Mask Sizes (2-D Fit Data)

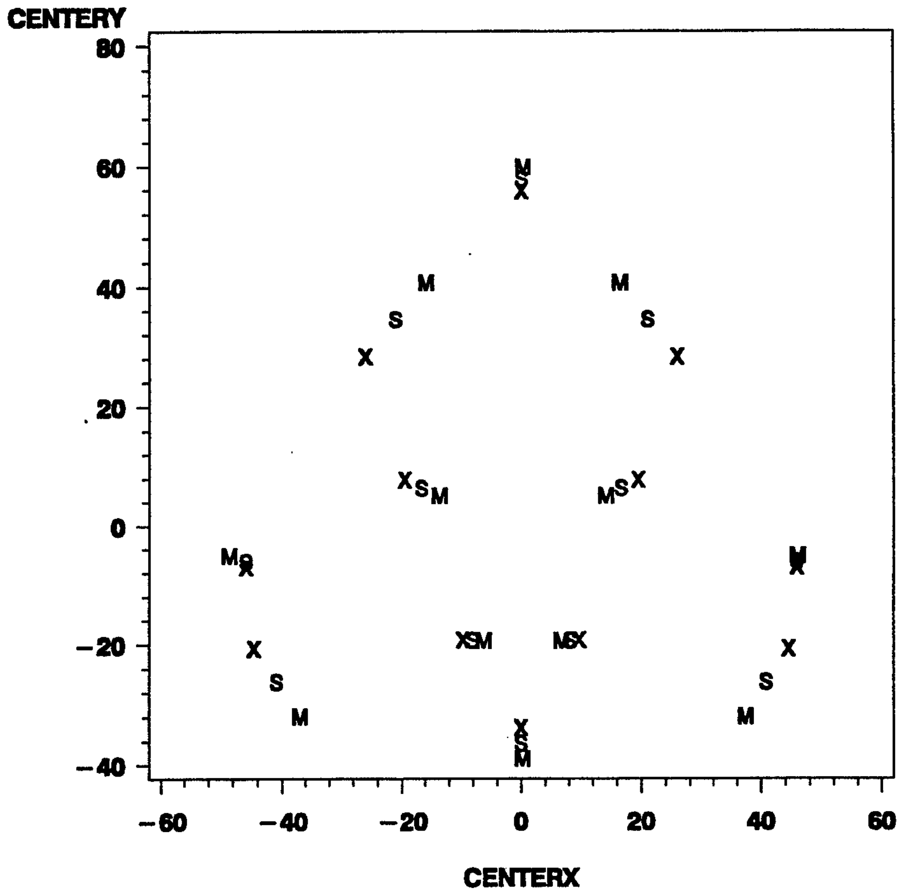


Figure 17. Comparison of Sizes Small-Narrow (S), Medium-Narrow (M), and Extra Small-Narrow (X)

CONCLUSIONS

Even though facial measurement variability was included as sampling strata, many of the strata were not filled for the women. In other words, the sampling protocol was violated in two respects for the female data. As a result, the female data are biased toward good fit, and are not adequately representative of the female population variability. It is reasonable to assume that the spread of the female data should correspond to the spread of the male data. Thus, an XSN size may be needed. Due to the sampling protocol violations, these data are unreliable, and not suitable for accurate probabilistic statements regarding fit. Furthermore, the lack of PPG experience for women rendered their fit questionnaire responses suspect. All was not in vain, however. The anthropometry of these women is still useful as one small part of a much-needed larger data base being collected for future design applications.

Complicating the analysis is the fact that compromises due to logistical limitations had to be made while planning the data collection procedures. Referring back to Figure 1 on page 2, the data collection flow chart indicates that traditional anthropometry was collected after the mask was fitted and tested on the subject and before the subject was scanned wearing it. Therefore, the subject removed the mask and then replaced it before being scanned. Before being scanned, many of the subjects did not don the mask as trained according to T.O. specifications; therefore, many were not wearing the mask for the scan the same way they wore it when they completed the wear test and fit questionnaire. The difference in placement could mean the difference between a pass and a fail as described in the recommendations on page 29. Given the degree of mask displacement evident in the scans, the fit data may not correlate well to the mask-seal interface. Without this correlation, there is no way to truly determine what anthropometric differences exist between a pass and fail. Had we found differences, they would have been questionable.

As stated earlier, the goal of this study was to determine sizing recommendations to improve the fit of the MBU-20/P by either reshaping the existing mask or adding new sizes. The AAOM dataset, however, provided us with little or no information to make such recommendations based on anthropometry. An attempt was made to create three new sizes by applying proportional relationships between sizes to existing sizes. This method is based on the assumption that the relationships between sizes are appropriate. In this case, they were not. A technique to refine the method is suggested.

Clearly, the factor of primary importance in quality of fit within a size is the placement of the mask on the face. There were no detectable differences in facial anthropometry within a size between subjects who passed and those who failed. While no differences were found, that does not mean they do not exist. The scale of importance of the mask placement in this analysis could be masking any effects due to differences in anthropometry. Furthermore, a lack of correlation between the scan data and the fit questionnaire data may prevent detection of differences. When differences are hidden, there is no way to describe them based on statistical data.

The importance of mask placement is supported by all statistical analyses and is further supported by the small fit test (n=5) to compare sizes MN and MW. All subjects that were retested in a size changed overall score. This demonstrates that mask placement is crucial. All pilots must understand the importance of this placement, because it could mean the difference between life and death. Further fit testing with correct mask placement and proper data collection procedures may show these differences. This result can also have implications for the mask customization process. Proper adherence to the mask placement criteria in T.O. 14P3-1-161 can be used in the customization process to determine where to extract the facial contour for creating the customized mask.

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APPENDIX A

Combat Edge Mask Grinding Checklist

COMBAT EDGE MASK GRINDING CHECKLIST

NAME____________________ DATE ___________

TIME ___________

Instructions: When finished fitting each pilot, indicate in the trial number the number of times you have fit this individual. Using the checklist, indicate the problems associated with each facial region, (**L** for leakage or **P** for excessive pressure), rate the severity of the problem using the scale provided, and record if grinding is required in that particular facial region. Use the last two rows to indicate your opinion as to the **overall** severity of leaks and pressure associated with the mask (these ratings should take all facial regions into consideration at once).

NOTE: This form should be completed the first time the pilot is fit, **and each subsequent time** that a pilot is seen in order to correct fit problems.

TRIAL # ______

FACIAL REGION	LEAK/ PRESSURE	RATING 1	2	3	4	GRINDING REQUIRED?
A. Bridge of Nose	L					Y N
	P					Y N
B. Right Side of Nose	L					Y N
	P					Y N
C. Left Side of Nose	L					Y N
	P					Y N
D. Right Cheek	L					Y N
	P					Y N
E. Left Cheek	L					Y N
	P					Y N
F. Chin	L					Y N
	P					Y N
G. Other (Specify)	L					Y N
	P					Y N
OVERALL RATING	L					
	P					

RATING KEY

Leaks **1: No Leaks, 2: Slight Leakage, 3: Moderate Leakage, 4: Excessive Leakage**

Pressure normal **1: Normal Pressure, 2: Slightly above normal pressure, 3: Moderately above pressure, 4: Excessively above normal pressure**

APPENDIX B

Consent Form

Protocol 83-30
(15 Feb 94)

INFORMATION PROTECTED BY THE PRIVACY ACT OF 1974

Consent Form

TITLE: ANTHROPOMETRY - Advanced Aircrew Oxygen Mask (AAOM) Program

1. You are invited to participate in an experiment in which we will measure the body sizes and surfaces of individuals for use in the sizing and design of clothing and personal protective equipment or of aircraft and ground equipment crew and work stations.

2. If you decide to participate, we will measure a number of dimensions on your body. These will describe the lengths, breadths, depths, circumferences, and surface contours of your body and its major segments. To aid in this process, measuring marks will be placed on your body with a water soluble colored pencil or gummed back stickers. These will be removed after measuring is completed. Measurements are made with several types of devices. One is a device which is similar to a yard stick called an anthropometer. Also used are tape measures and various types of calipers. Another is a light scanner which will project a line of light from a very low power laser onto your skin surface. This light will be moved around you and will be recorded in a video camera. We have measured many thousands of men and women with no adverse effects.

3. Your confidentiality as a participant in this program will be protected. If statistical data collected during the test program is to be published in scientific literature, it will be done so without identifying individual subjects.

4. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice to your future relations with the Armstrong Laboratory. If you have any questions, please feel free to contact Kathleen M. Robinette, AL/CFHD, Building 248, 2255 H Street, Wright-Patterson AFB OH 45433-7022, (513) 255-8810.

5. I, ________________________________, am participating because I want to. The decision to participate in this research study is completely voluntary on my part. No one has coerced or intimidated me into participating in this program. ____Capt Jeffrey W. Hoffmeister____ has adequately answered any and all questions I have asked about this study, my participation, and the procedures involved, which are set forth above, which I have read. I understand that the Principal Investigator or a designee will be available to answer any questions concerning procedures throughout this study. I understand that if significant new findings develop during the course of

____
Volunteer signature

this research which may relate to my decision to continue participation, I will be informed. I further understand that I may withdraw this consent at any time and discontinue further participation in this study. I also understand that the Medical Consultant for this study may terminate my participation in this study if it is felt to be in my best interest.

6. I understand that for my participation in this project I shall be entitled to payments as specified in the DOD Pay and Entitlements Manual or in the current contracts. Or, I understand that I will not be paid for my participation in this experiment.

7. I understand that my participation in this study may be photographed, filmed, or audio/video taped. I further understand that the scan produces a laser image which itself is a numeric photo. I consent to the use of these media for research and training purposes and understand that any release of records of my participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 U.S.C. 552a, and its implementing regulations. This means personal information will not be released to an unauthorized source without my permission.

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

______________________________ ______________

Volunteer signature and SSAN Date

______________________________ ______________

Witness signature Date

______________________________ ______________

Principal Investigator signature Date

INFORMATION PROTECTED BY PRIVACY ACT OF 1974

Authority 10 U.S.C. 8012, Secretary of the Air Force; powers and duties; delegation by; implemented by DOI 12-1, Office Locator.

Purpose is to request consent for participation in approved medical research studies. Disclosure is voluntary.

Routine Use Information may be disclosed for any of the blanket routine uses published by the Air Force and reprinted in AFP 12-36 and in Federal Register 52 FR 16431.

APPENDIX C

Combat Edge Fit Assessment Questionnaire

COMBAT EDGE FIT ASSESSMENT QUESTIONNAIRE

Name ______________________________ Date ____________

HGU-55/P HELMET SIZE: _____

COMBAT EDGE MASK SIZE: SNar MNar MWide LWide

How many sorties have you flown with the COMBAT EDGE mask? _______

Have you flown using PPG? YES NO If yes, how many sorties? _______

Has the hardshell of your COMBAT EDGE mask been ground (customized) YES NO

Key for questions 1-3 -- 1: Comfortable, 2: Tolerable, 3: Irritating, 4: Acute and lingering pain, have to drop mask.

1. Rate each facial region for comfort of the pressure applied by the COMBAT EDGE mask..

Locations (Refer to Diagram)	Comfort				
	Comfortable	Slightly Uncomfortable	Moderately Uncomfortable	Very Uncomfortable	Hot Spot?
	1	2	3	4	
A. Bridge of Nose					
B. Right side of Nose					
C. Left side of Nose					
D. Right Cheek					
E. Left Cheek					
F. Chin					
G. Other (List)					

2. How would you rate the comfort of the COMBAT EDGE mask at high G? Highest G? _____

Comfortable	Slightly Uncomfortable	Moderately Uncomfortable	Very Uncomfortable	Hot Spot?
1	2	3	4	5

3. How would you rate the COMBAT EDGE mask for *OVERALL COMFORT*?

Comfortable	Slightly Uncomfortable	Moderately Uncomfortable	Very Uncomfortable	Hot Spot?
1	2	3	4	5

Key for question 4 -- 1: None, 2: Slight shift on face, 3: Needs repositioning, 4: Seal is broken

4a. How would you rate the SLIPPAGE of the COMBAT EDGE mask?

No Slippage	Slight Slippage	Moderate Slippage	Excessive Slippage
1	**2**	**3**	**4**

4b. If your mask slipped, at what G load did it first begin to slip? _____

4c. Do you think the slippage was due to a poor fit as opposed to perspiration, skin oil, etc.?
Y N U

Key for questions 5-6 -- 1: None, 2: Noticeable, 3: Irritates the eyes, 4: Burns the eyes.

5. Identify the severity of leaks for each facial region.

Locations (Refer to Diagram)	Severity			
	No Leaks	Slight Leakage	Moderate Leakage	Excessive Leakage
	1	**2**	**3**	**4**
A. Bridge of Nose				
B. Right side of Nose				
C. Left side of Nose				
D. Right Cheek				
E. Left Cheek				
F. Chin				
G. Other (List)				

6. How would you rate the *OVERALL SEAL* of the mask?

Excellent	Good	OK or Average	Fair	Poor
1	**2**	**3**	**4**	**5**

7. In general, how would you classify the fit (comfort, slippage, leakage) of the mask?

Excellent	Good	OK or Average	Fair	Poor
1	**2**	**3**	**4**	**5**

8. How did the fit of the mask degrade your *PERFORMANCE?*

No Degradation	Slight Degradation	Moderate Degradation	Excessive Degradation
1	**2**	**3**	**4**

9a. Did you take any actions (e.g., equipment adjustments) to correct for comfort, slippage or leakage? Y N

9b. If yes, what actions did you take to address each problem, and did your actions correct the problems?

____

____

10. Does the microphone touch or interfere with your nose? Y N

11. Does the microphone touch or interfere with your mouth? Y N

12a. Are you satisfied with how the mask hangs while disconnected? Y N

12b. If no, explain ____

Additional Comments:

____

____

____

____

____

APPENDIX D

AAOM Anthropometry

AAOM ANTHROPOMETRY

SUBJECT NUMBER ____________ **DATE** ______________________________

NAME ________________________ **TEST LOCATION** ___________________

RANK ________________________ **AF SPECIALTY CODE** ________________

AGE ________________________ **MAJCOM** _________________________

RACE: W B A H Other

SEX: M F

====================== DO NOT WRITE BELOW THIS LINE ======================

SCAN FILE NAMES: ______________________
____
____
____

MEASUREMENTS TAKEN WITHOUT CAP (mm)

Head Circumference	_______	Bi-Inframalar	_______
Bitragion-Subnasale Arc	_______	Lip Length	_______
Head Length	_______	Lip Length, Smiling	_______
Head Breadth	_______	Nasal Root Breadth	_______
Bizygomatic Breadth	_______	Nose Breadth	_______
Menton-Sellion Length	_______	Nose Length	_______
Sellion-Supramenton	_______	Nose Protrusion	_______
Menton-Subnasale Length	_______		

MEASUREMENTS TAKEN WITH CAP

Head Circumference	_______	Head Breadth	_______
Head Length	_______		

Measurer ________________________________

Recorder ________________________________

APPENDIX E

Anatomical Landmark Description

Auxiliary Landmark Description

TRADITIONAL ANTHROPOMETRIC LANDMARK DESCRIPTIONS

FRONTOTEMPORALE (L6, L26): The point of deepest indentation of the temporal crest from the frontal bone above the browridges.

GLABELLA (L12) - The most anterior point in the midline of the forehead between the brow ridges. Located visually and by palpation before traditional anthropometry.

INFRAMALAR (L8, L28) - The most inferior point of the zygomatic process of the maxilla. Located by palpation before traditional anthropometry.

INFRAORBITALE (L11, L22) - The lowest point on the inferior margin of the orbit or eye socket. Located by palpation before traditional anthropometry.

MENTON (L17): The inferior point of the mandible (tip of the chin) in the midsagittal plane.

NUCHALE (L33)- The lowest bony point on the base of the back of the skull in the mid-sagittal plane. Located by palpation before traditional anthropometry.

PROMENTON (L16)- The most anterior projection of the soft tissue of the chin in the mid-sagittal plane. Located visually before traditional anthropometry.

PRONASALE (L14) - The tip of the nose. Located visually before traditional anthropometry.

SELLION (L13) - The point of greatest indentation where the bridge of the nose meets the forehead (the point of greatest indentation of the nasal root depression). Located visually before traditional anthropometry.

SUPRAMENTON (L42) - The point of deepest depression under the lower lip in the midline of the face. Located visually before traditional anthropometry.

TRAGION (L1, L32) - Point located at the notch just above the tragus of each ear. this point corresponds approximately to the upper edge of the ear hole (external auditory meatus) of the skull. Located visually before traditional anthropometry.

ZYGION (L2, L29) - The most lateral point of the zygomatic arch. Located before traditional anthropometry using spreading calipers to identify widest set of points.

* Landmark names followed by two identifiers indicates “right” and “left”.

AUXILIARY LANDMARKS DESCRIPTIONS

UPPER RIGHT RIVET (Z1) - The upper right rivet on the mask hardshell.

UPPER LEFT RIVET (Z2) - The upper left rivet on the mask hardshell.

UPPER RIGHT PENTAGON (Z3) - The upper right corner of the “pentagon” on the front of the MBU-20/P mask hardshell.

UPPER LEFT PENTAGON (Z4) - The upper left corner of the “pentagon” on the front of the MBU-20/P mask hardshell.

LOWER RIGHT PENTAGON (Z5) - The lower right corner of the "pentagon" on the front of the MBU-20/P mask hardshell.

LOWER LEFT PENTAGON (Z6) - The lower left corner of the "pentagon" on the front of the MBU-20/P mask hardshell.

RIGHT HELMET DIMPLE (Z7) - The lower dimple on the right side of the HGU-55/P helmet.

MID-FRONT EDGEROLL (Z8) - The mid-point of the front edgeroll on the HGU-55/P helmet.

LEFT HELMET DIMPLE (Z9) - The lower dimple on the left side of the HGU-55/P helmet.

RIGHT BAYONET (Z10) - A point on the end of the bayonet attached to the right side of the MBU-20/P mask (as worn by subject with HGU-55/P helmet).

LEFT BAYONET (Z11) - A point on the end of the bayonet attached to left side of the MBU-20/P mask (as worn by subject with HGU-55/P helmet).

MID Z1-Z2 (Z12) - The Mid-point of landmarks Z1 and Z2 (used to help define mask-axis system).

MID Z5-Z6 (Z13) - The Mid-point of landmarks Z5 and Z6 (used to help define mask-axis system).

TOP-MID MASK (Z14) - A point at the top-middle of the nose region on the MBU-20/P mask hardshell.

BOTTOM-MID MASK (Z15) - A point at the bottom-middle of the chin region on the MBU-20/P mask hardshell.

MIN RIGHT (Z16) - The minimum curvature inflection point on the right side of the MBU-20/P mask hardshell.

MIN LEFT (Z17) - The minimum curvature inflection point on the left side of the MBU-20/P mask hardshell.

MAX RIGHT (Z18) - The maximum curvature inflection point on the right side of the MBU-20/P mask hardshell.

MAX LEFT (Z19) - The maximum curvature inflection point on the left side of the MBU-20/P mask hardshell.

MAX BOTTOM-RIGHT (Z20) - The maximum curvature inflection point on the bottom-right of the MBU-20/P mask hardshell.

MAX BOTTOM-LEFT (Z21) - The maximum curvature inflection point on the bottom-left of the MBU-20/P mask hardshell.

MID-NOSEBRIDGE (Z22) - The point on the bridge of the nose half-way between Sellion and Pronasale. Located visually in three-dimensional surface scan data.

RIGHT ALARE (Z23) - The most lateral point on the right side of the nose. Located visually in three-dimensional surface scan data.

LEFT ALARE (Z24) - The most lateral point on the left side of subject's nose. Located visually in three-dimensional surface scan data.

APPENDIX F

Definitions of AAOM Anthropometry

DEFINITIONS OF AAOM ANTHROPOMETRY

BI-INFRAMALAR BREADTH - The straight-line distance is measured between the right and left inframalar (the most inferior point of the zygomatic process of the maxilla) landmarks.

BITRAGION-SUBNASALE ARC - The surface distance is measured between the right and the left tragion (Tragion is the point where the top of the cartilaginous flap at the front of the ear joins the head) with a tape passing across the face at the center of the juncture of the nose with the face above the upper lip (subnasale).

BIZYGOMATIC BREADTH - The maximum horizontal distance is measured across the face between the upper cheek bones (zygomatic arches).

HEAD BREADTH - The maximum horizontal breadth of the head above the ears is measured.

HEAD CIRCUMFERENCE - The maximum circumference of the head is measured in a front-to-back plane with the tape passing just above the bony brow ridges and over the most protruding point of the back of the head.

HEAD LENGTH - The maximum straight line is measured between he most protruding point of the forehead between the brow-bridges and the back of the head.

LIP LENGTH - The subject closes the mouth with the facial muscles relaxed. The straight-line distance is measured between the corners of the mouth.

LIP LENGTH SMILING - The straight-line distance is measured between the corners of the mouth while the subject smiles broadly.

MENTON-SELLION LENGTH - The subject closes the mouth with the teeth lightly touching together. The straight-line distance is measured between the underside of the tip of the chin (menton) in the midline of the face and the point of deepest depression at the top of the nose between the eyes (sellion).

MENTON-SUBNASALE LENGTH - The subject closes the mouth with the teeth lightly together. The straight-line distance is measured between the underside of the tip of the chin (menton) in the midline of the face and the center of the bottom of the nose where it joins the face above the upper lip (subnasale).

NASAL ROOT BREADTH - The breadth of the bridge of the nose is measured at its point of deepest depression at a depth of about two-thirds the distance between the top of the bridge and the inner corner of the eyes.

NOSE BREADTH - The horizontal breadth of the nose is measured at the level of the maximum flare of the nostrils.

NOSE LENGTH - The straight-line distance is measured between the point of deepest depression at the top of the nose between the eyes (sellion) and the center of the bottom of the nose where it joins the face above the upper lip (subnasale).

NOSE PROTRUSION - The horizontal distance is measured between the center of the juncture of the bottom of the nose with the face above the upper lip (subnasale) and the tip of the nose.

SELLION-SUPRAMENTON - The subject closes the mouth with the teeth touching lightly together. The straight-line distance is measured between the point of deepest depression under the lower lip in the midline of the face (supramenton) and the point of deepest depression at the top of the nose between the eyes (sellion).

APPENDIX G

Survey Comparisons for Sample Selection

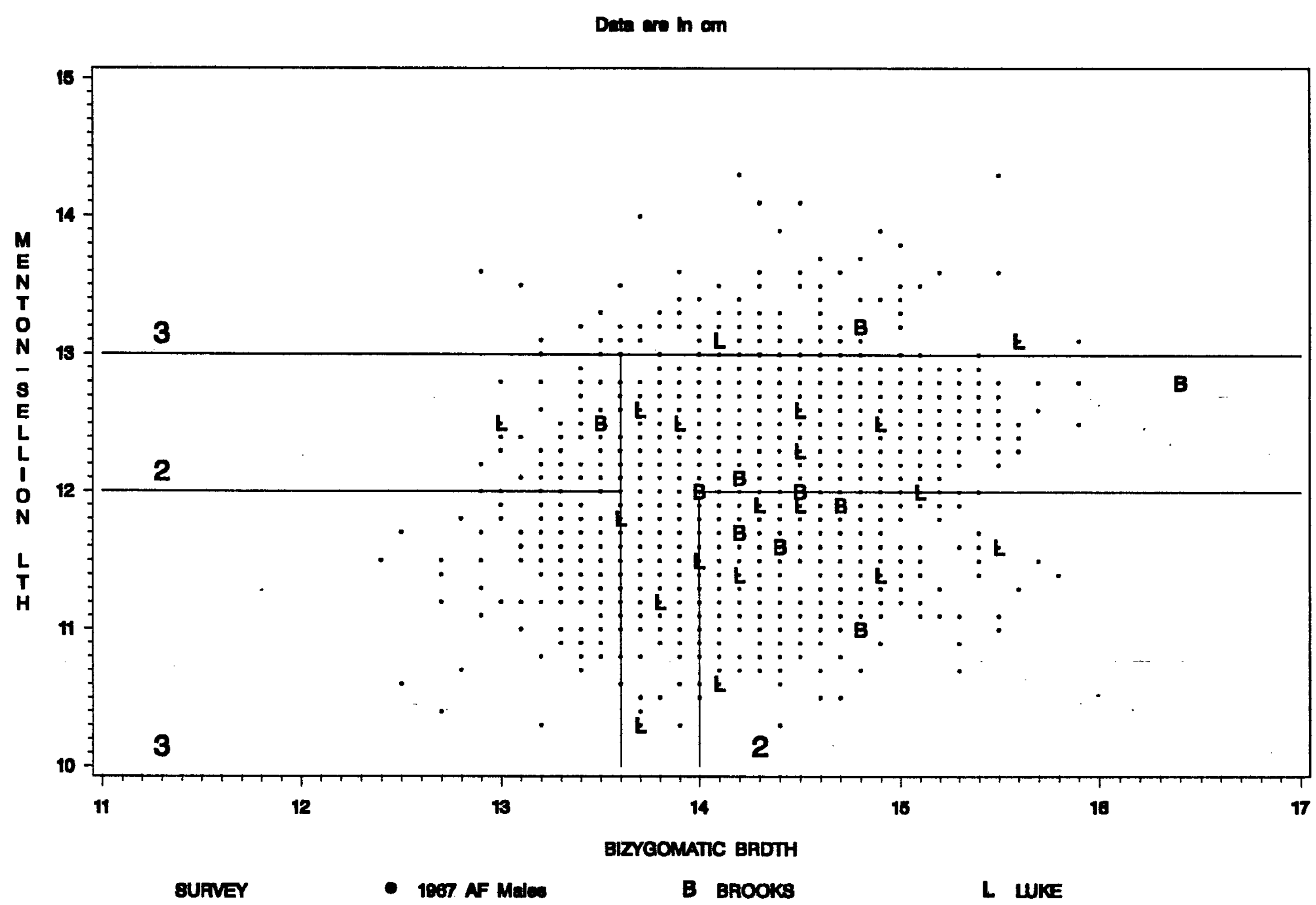


Figure G1. AAOM Males and 1967 Air Force Males Overlaid with Sampling Grid for Data Collection at Brooks AFB

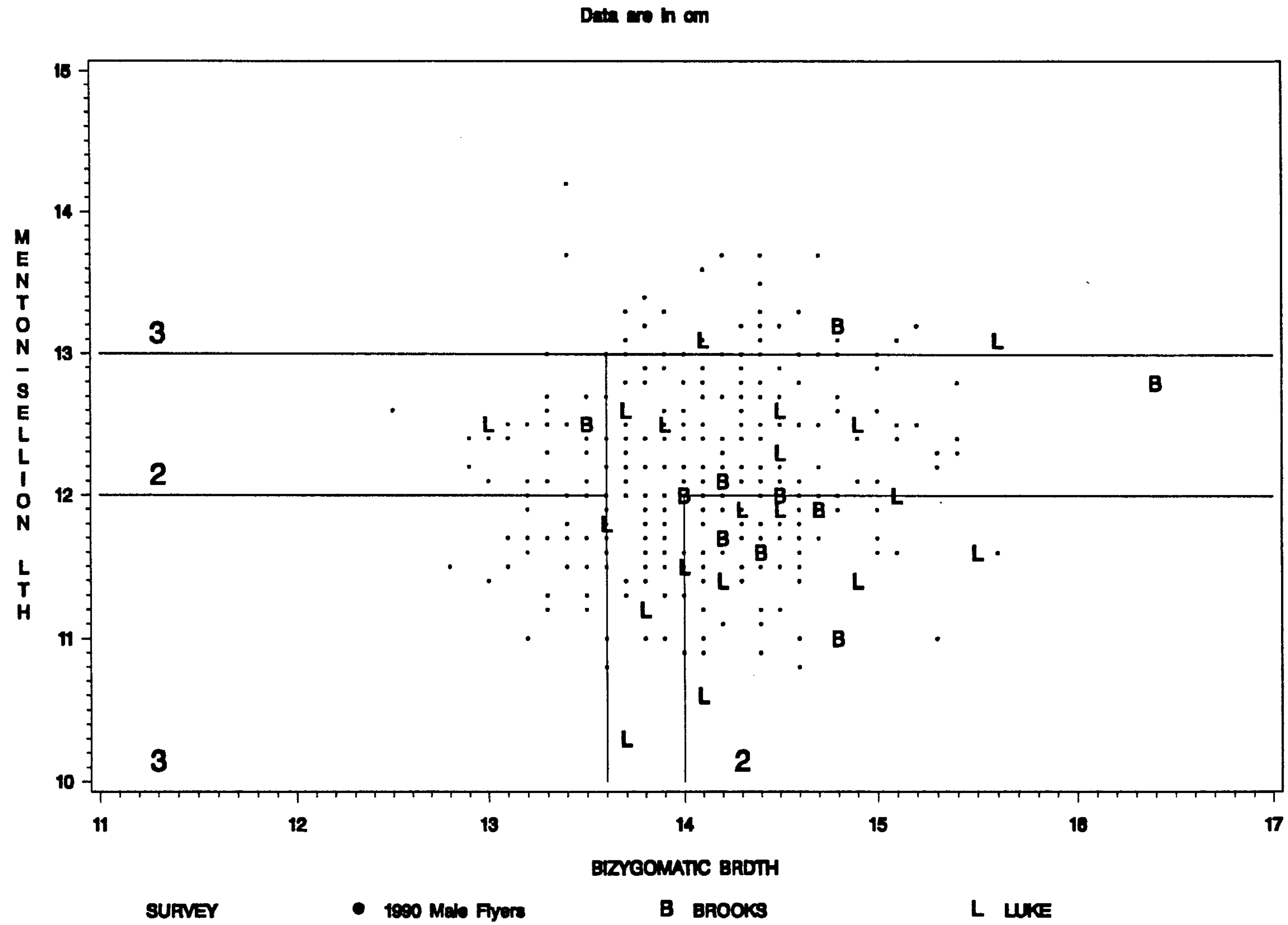


Figure G2. AAOM Males and 1990 Air Force Male Flyers Overlaid with Sampling Grid for Data Collection at Brooks AFB

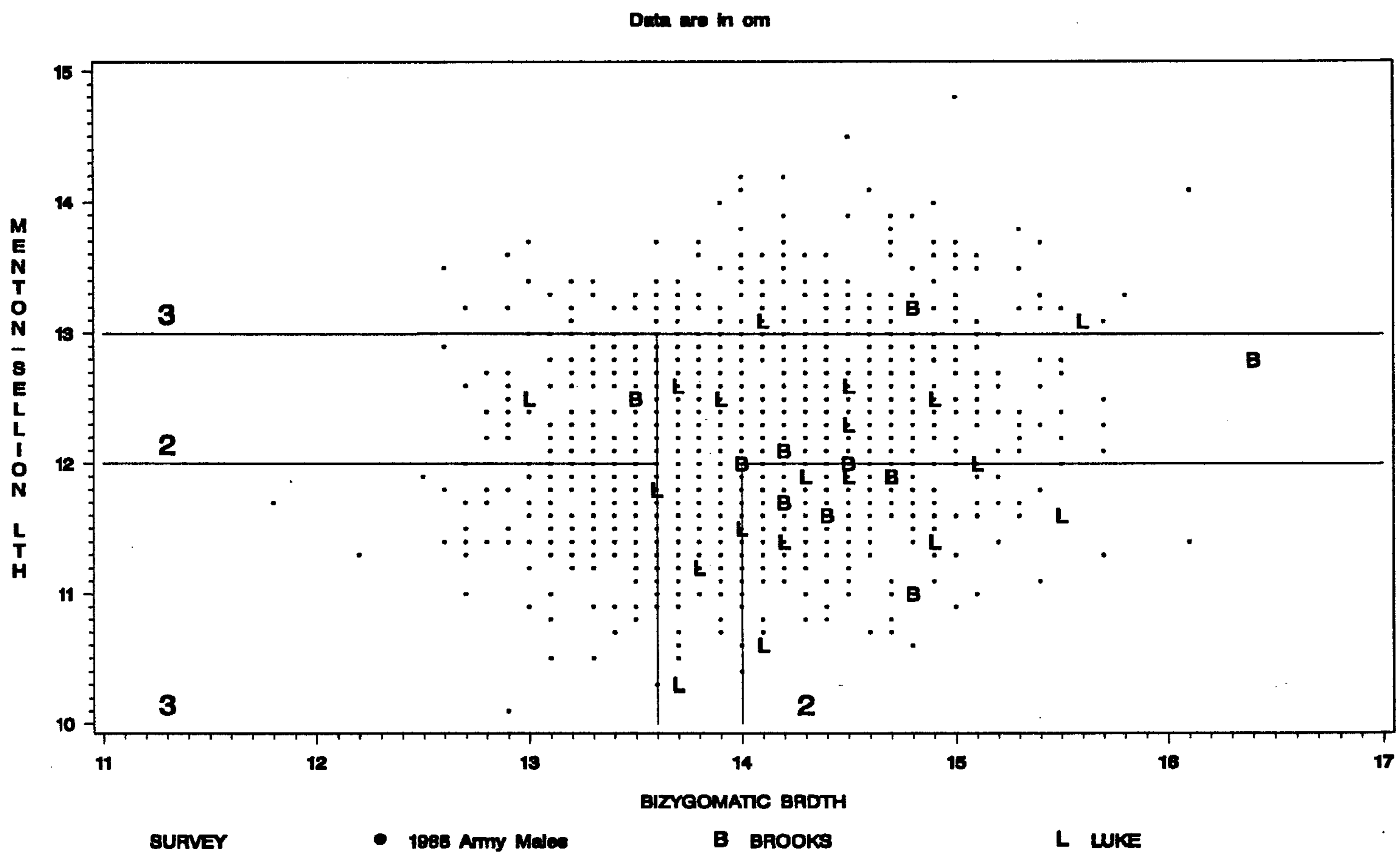


Figure G3. AAOM Males and 1988 Army Males Overlaid with Sampling Grid for Data Collection at Brooks AFB

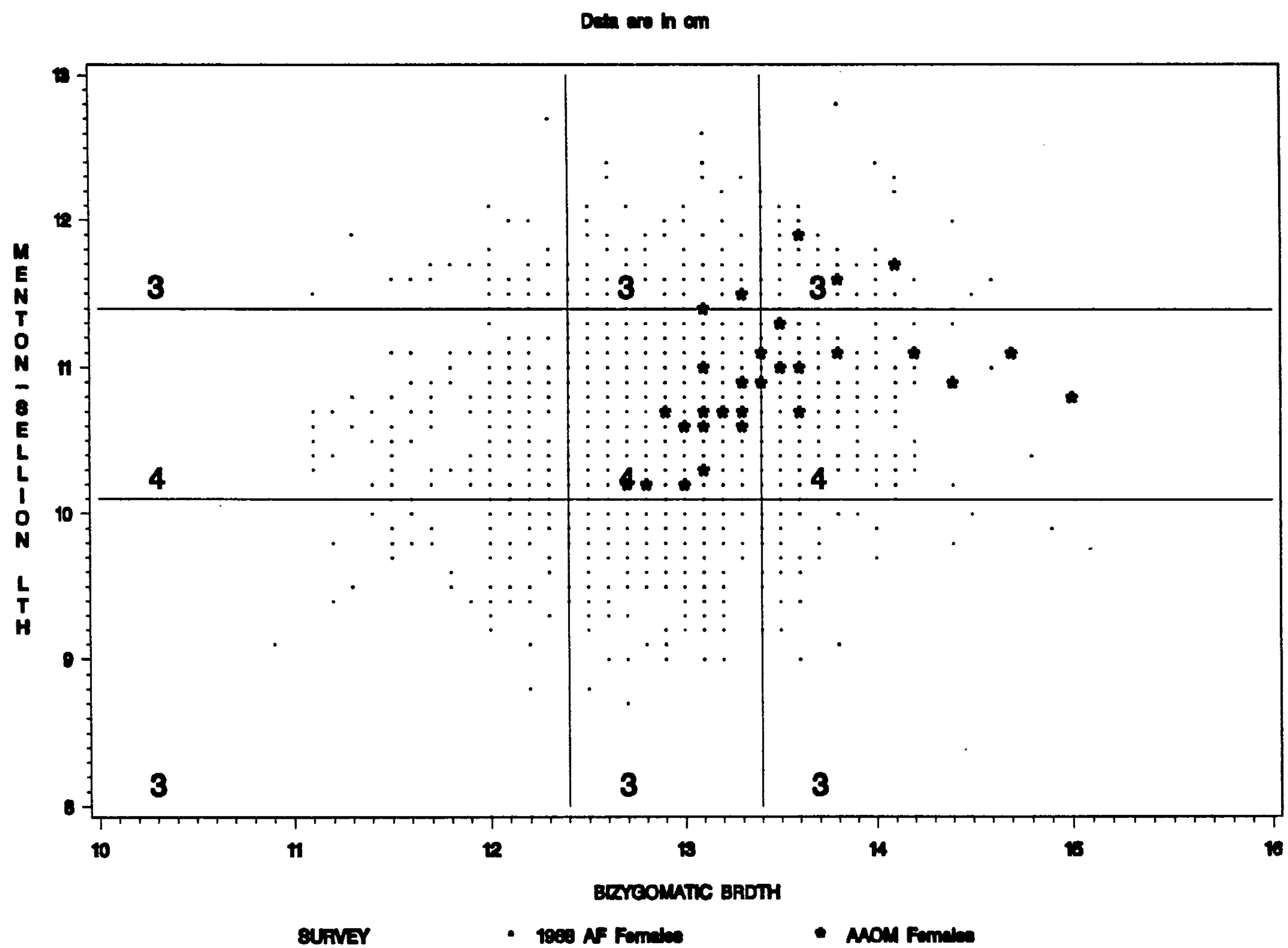


Figure G4. AAOM Females and 1968 Air Force Females Overlaid with Sampling Grid

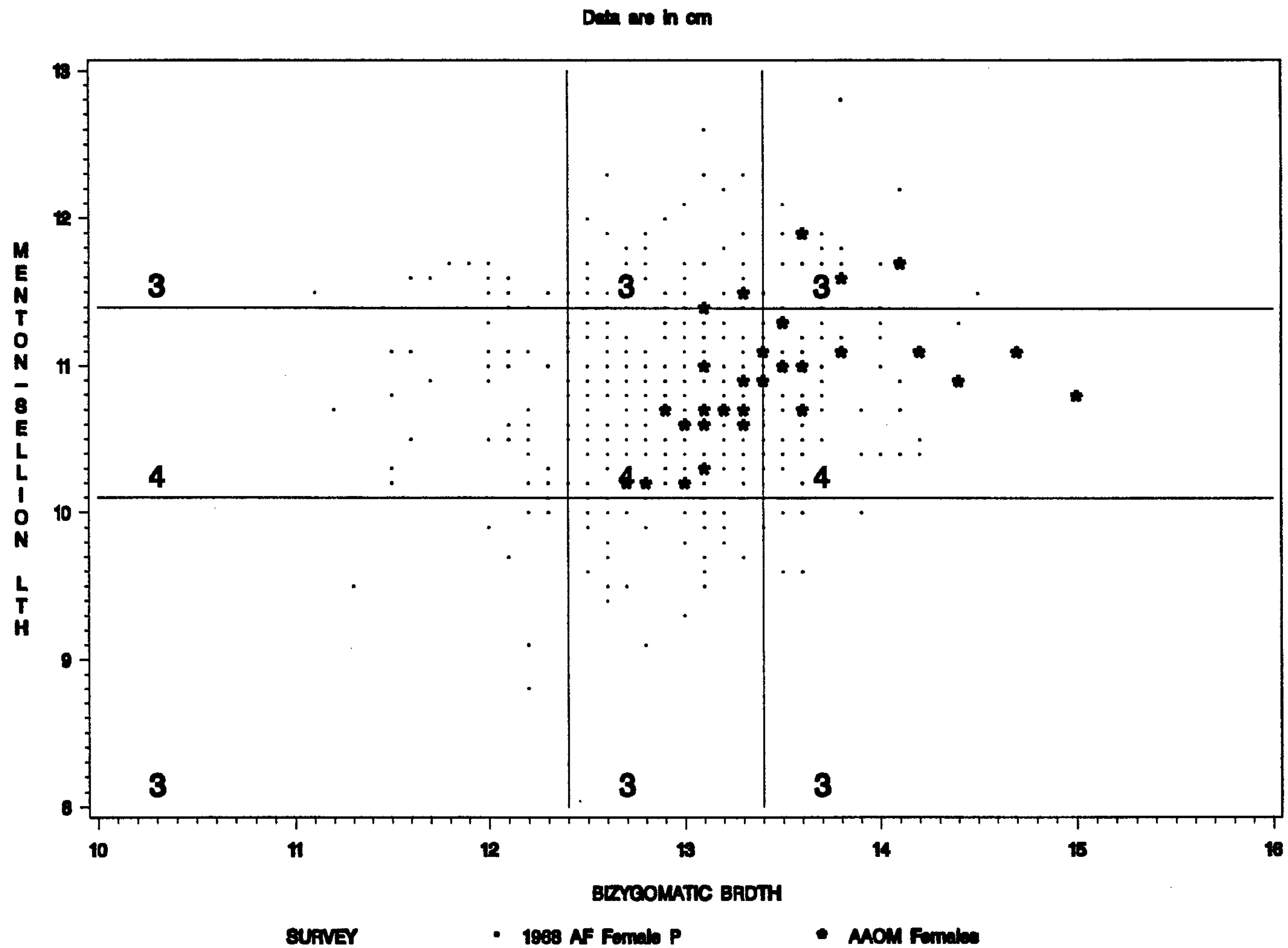


Figure G5. AAOM Females and 1968 Air Force Female Pilots Overlaid with Sampling Grid

APPENDIX H

AAOM Customization and Data Extraction Software

EXTEND is a CARD Lab tool developed specifically for AAOM. It projects the edge of the mask front onto a face scan. EXTEND matches the closest point on the face to get a more "natural" fit. For instance, a proper fitting mask extends nearly perpendicular to the face in the lower half of the mask, but extends more diagonally in the nose region, since a perpendicular fit is parallel to the surface of the nose. Accepting only the closest point also fails in the nose region, because the distance from the mask to the nose is very small, and the tendency was to try to go sideways toward the nose instead of backwards toward the main face surface. Experimentation indicated that an angle of no more than 15 degrees (from perpendicular to the face) in the lower face area and no more than 45 degrees in the nose region produced a profile similar to the shape of a standard mask. Another problem that the angular allowance reduced was the problem that the outer edges of the upper region of the mask actually project into the eye sockets unless some angular tolerance is allowed.

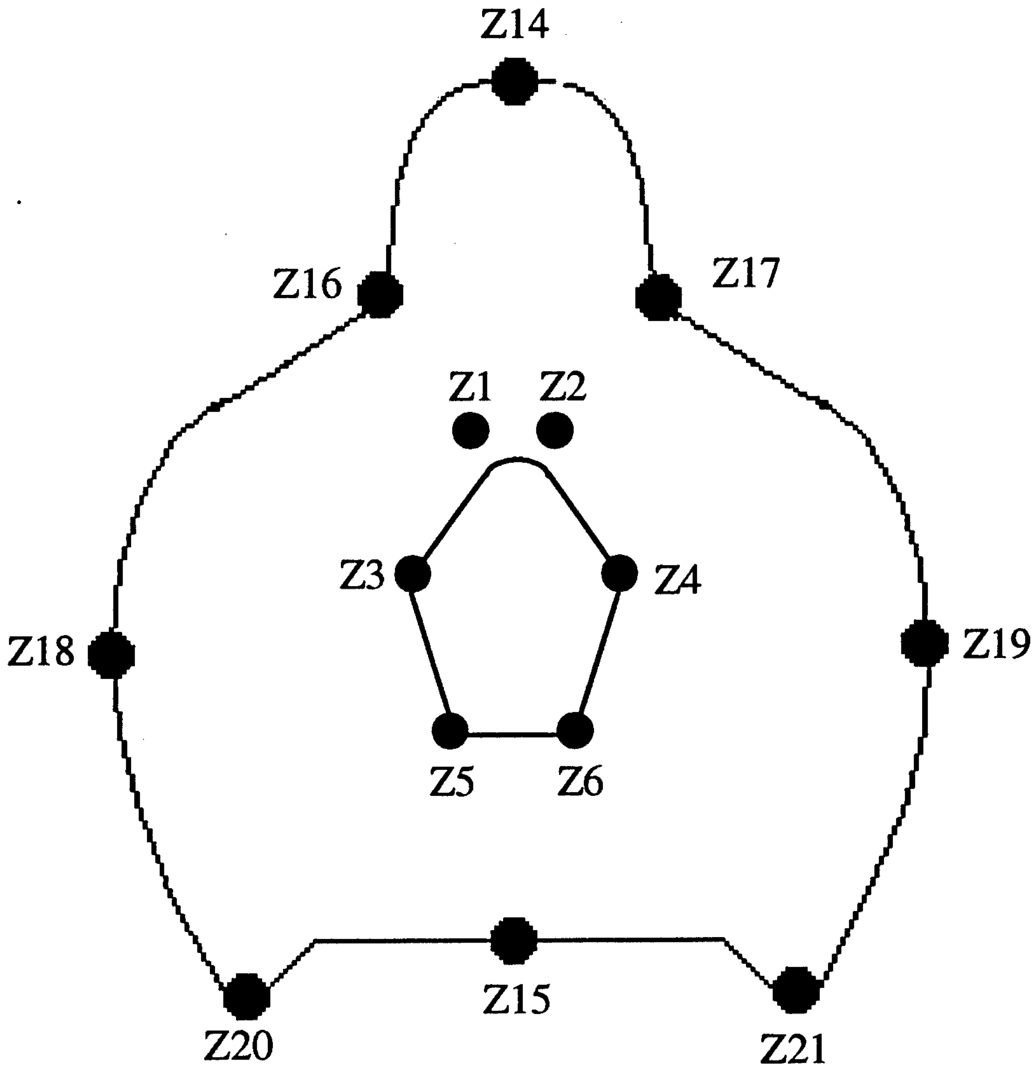
SEAL is a CARD Lab tool developed specifically for AAOM. It extracts the boundary of the seal area projected by the EXTEND tool described above and produces a set of points within the specified distance inside the seal boundary. This was used initially to extract the full area under the mask for the inside of a custom plug, but was also used later to extract just the points near the boundary for statistical analysis.

APPENDIX I

Landmarks used in the Euclidean Distance Matrix Analysis

Landmarks used in the Euclidean Distance Matrix Analysis

EDMA Landmark Number	Landmark Name
Z1	Upper Right Rivet
Z2	Upper Left Rivet
Z3	Upper Right Pentagon
Z4	Upper Left Pentagon
Z5	Lower Right Pentagon
Z6	Lower Left Pentagon
Z14	Top-Mid Mask
Z15	Bottom-Mid Mask
Z16	Min Right
Z17	Min Left
Z18	Max Right
Z19	Max Left
Z20	Max Bottom-Right
Z21	Max Bottom-Left
Z22	Mid-Nosebridge
Z23	Right Alare
Z24	Left Alare
L1	Right Tragion
L2	Right Zygion
L8	Right InfraMalar
L11	Right InfraOrbitale
L12	Glabella
L13	Sellion
L14	Pronasale
L16	Promenton
L22	Left InfraOrbitale
L28	Left InfraMalar
L29	Left Zygion
L32	Left Tragion
L42	Supramenton



Depiction of Mask Landmarks and Their Locations

APPENDIX J

Plots of Estimated Mask Seal Curvature

```
Arc Length Between 0 and 15 Percent
                      Regressed Third Order Polynomial
                            Data for Subject 001

                   Plot of X*S.      Symbol used is '*'.
                   Plot of XPRED*S.  Symbol used is 'P'.
```

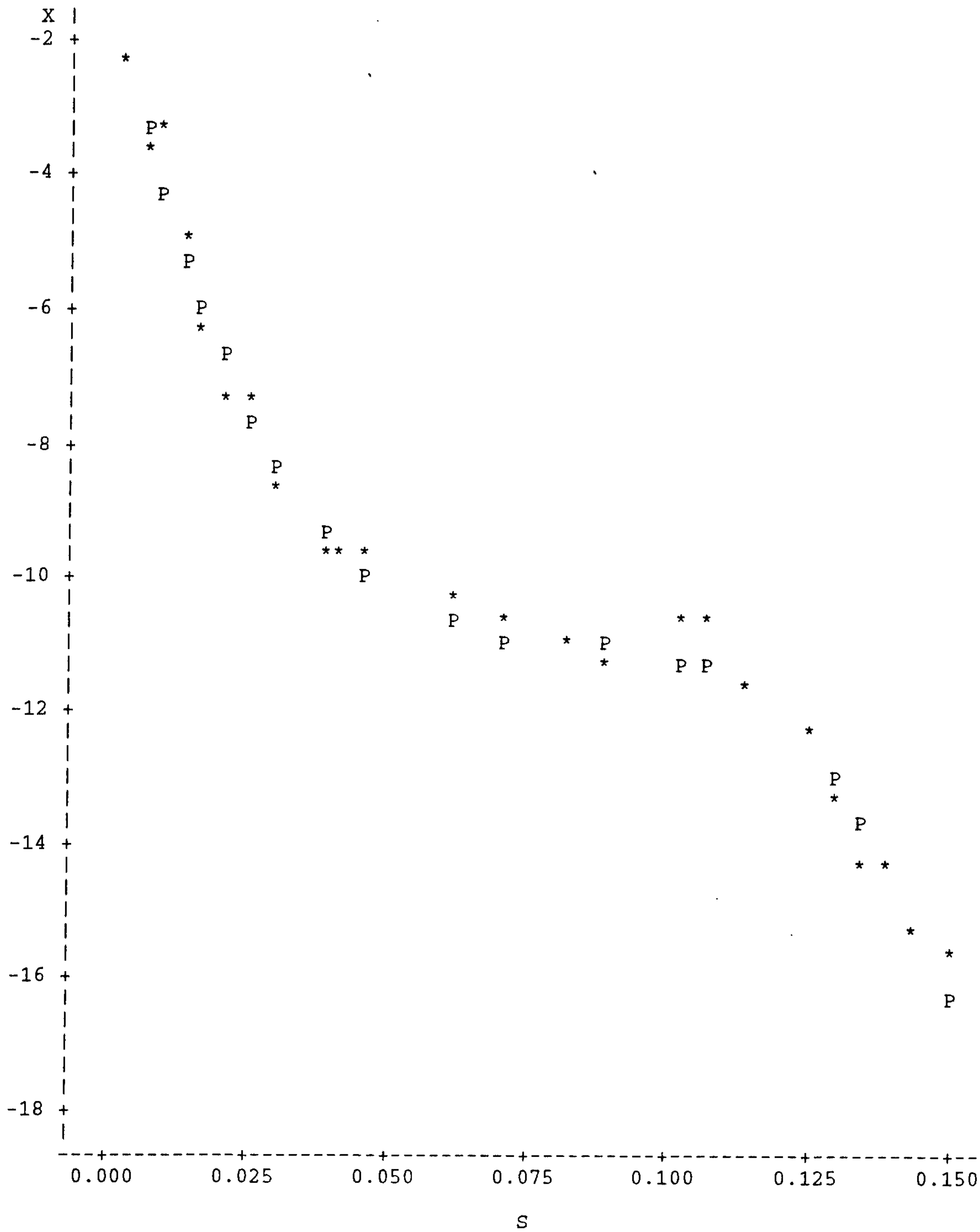


Figure J1. Arc Length Between 0 and 15 Percent for X With Respect To S

Arc Length Between 0 and 15 Percent
Regressed Third Order Polynomial
Data for Subject 001

Plot of Y*S.   Symbol used is '*'.
Plot of YPRED*S. Symbol used is 'P'.

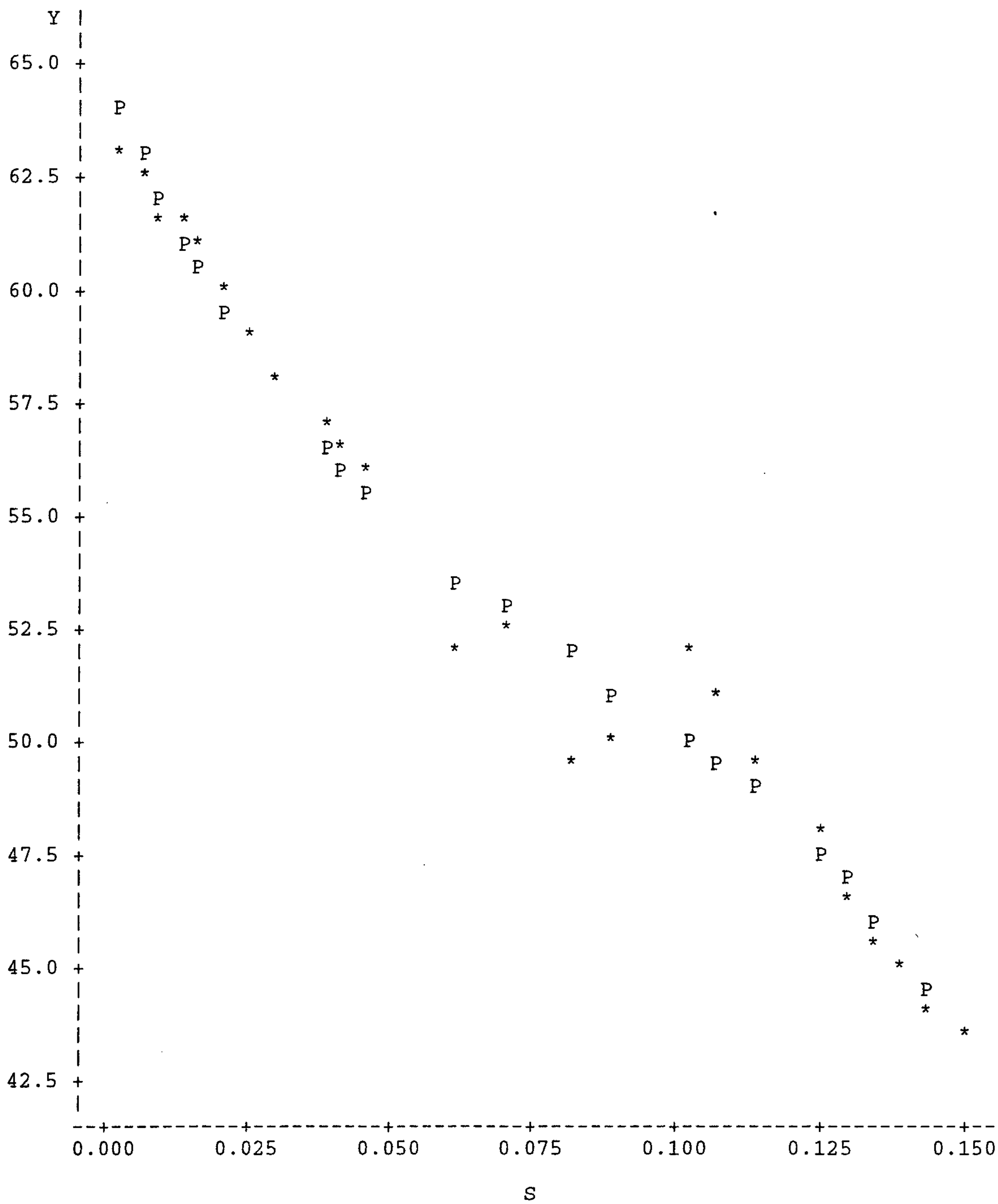


Figure J2. Arc Length Between 0 and 15 Percent for Y With Respect To S

Arc Length Between 0 and 15 Percent
Regressed Third Order Polynomial
Data for Subject 001

Plot of Z*S.   Symbol used is '*'.
Plot of ZPRED*S. Symbol used is 'P'.

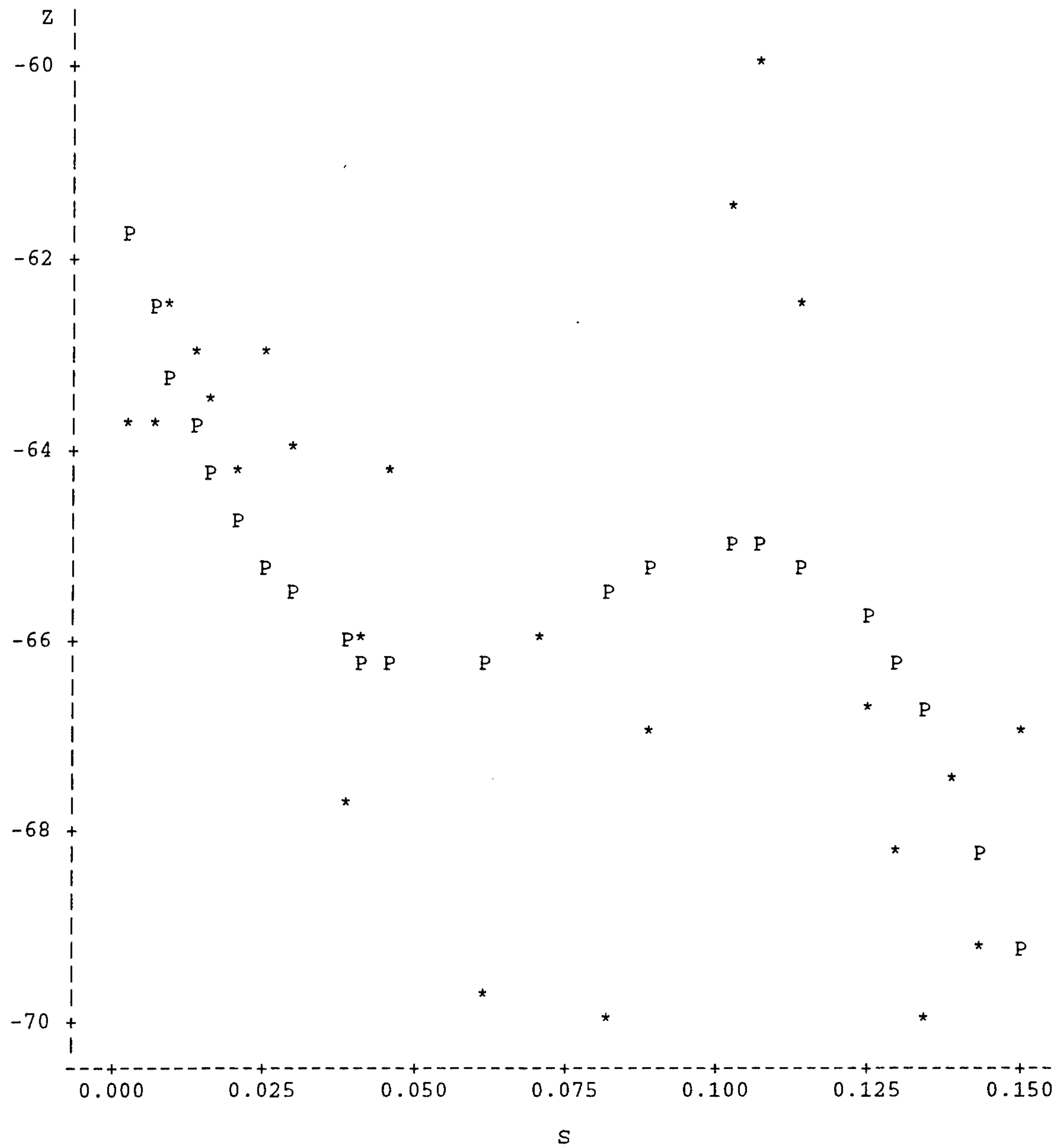


Figure J3. Arc Length Between 0 and 15 Percent for Z With Respect To S

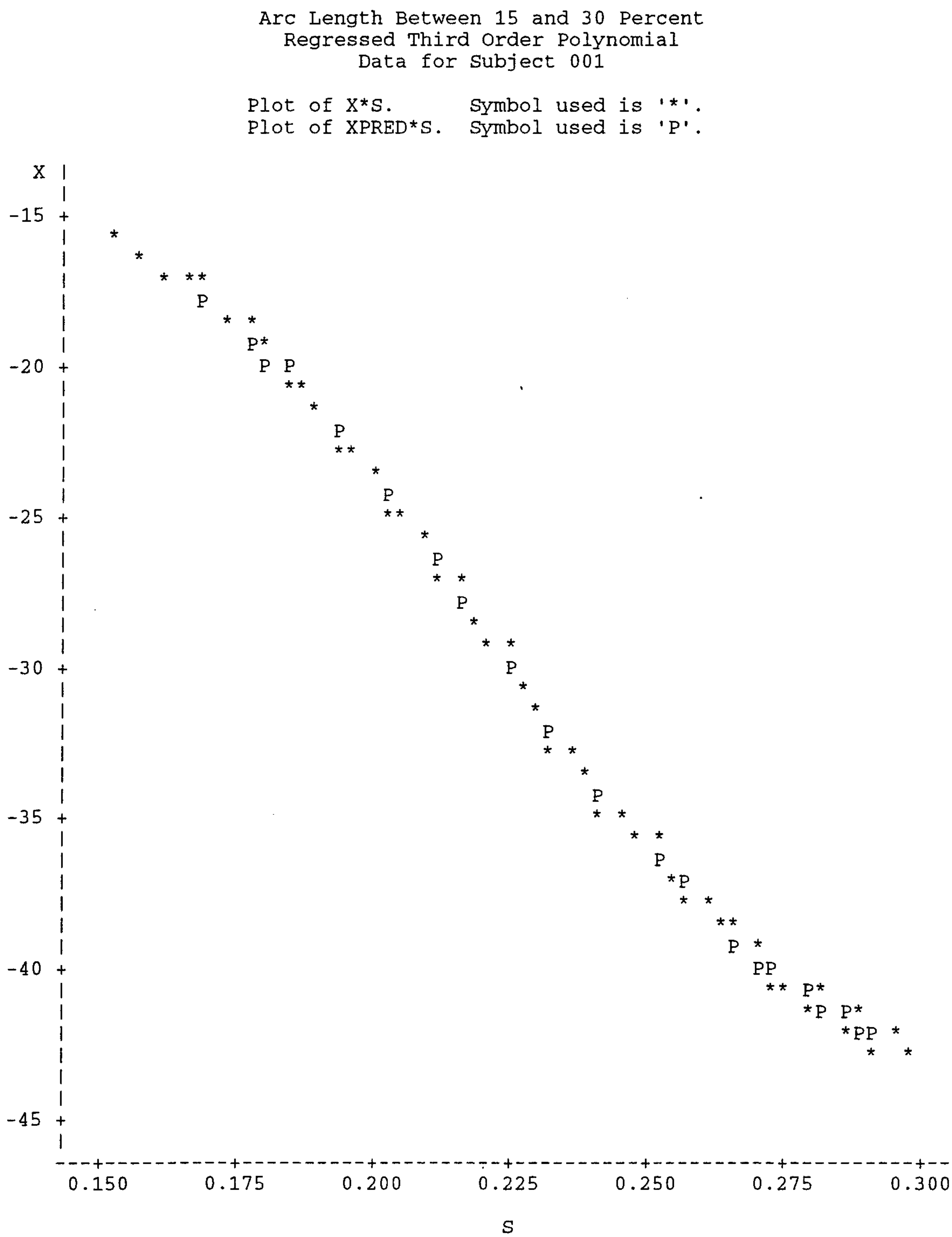


Figure J4. Arc Length Between 15 and 30 Percent for X With Respect To S

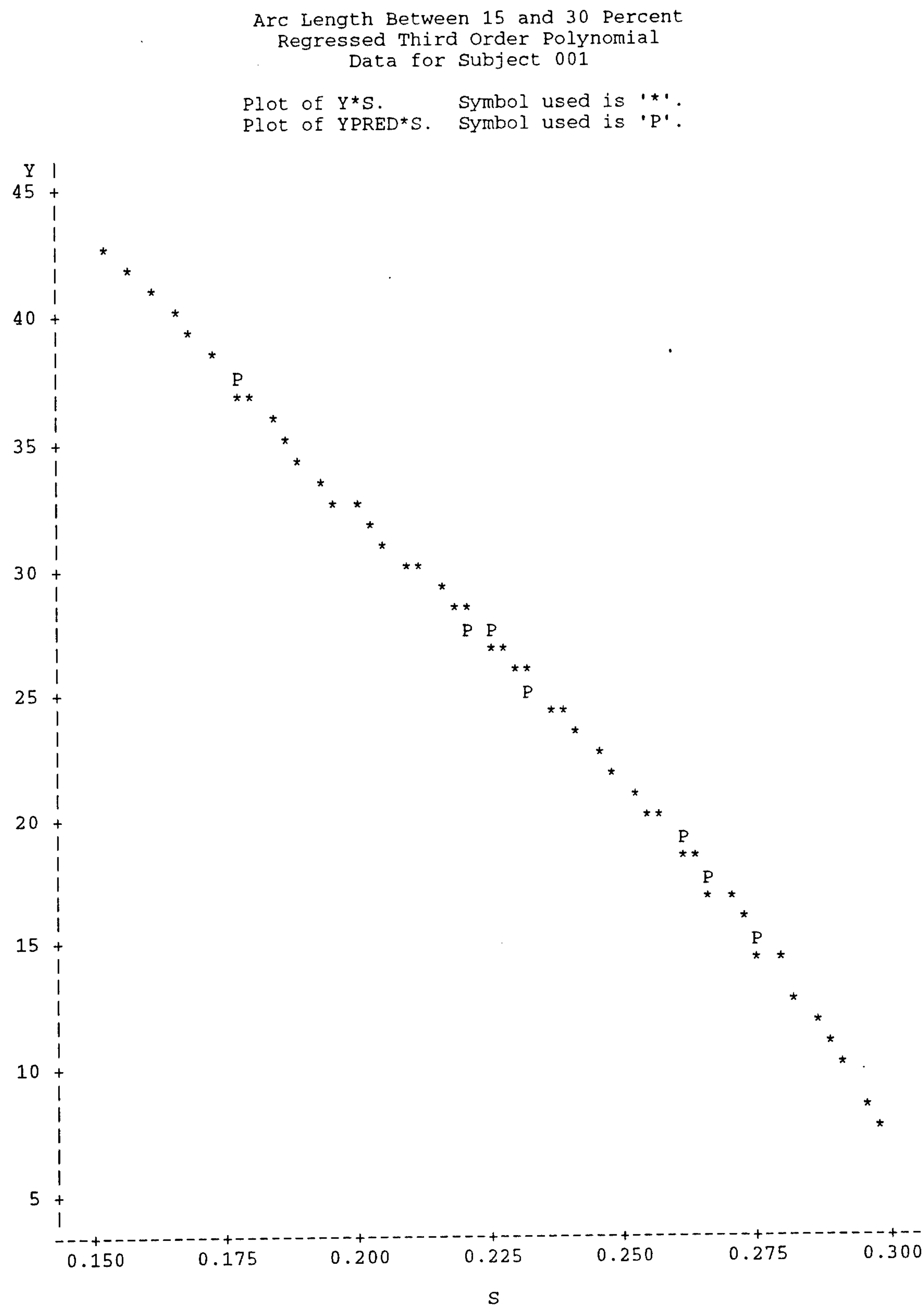


Figure J5. Arc Length Between 15 and 30 Percent for Y With Respect To S

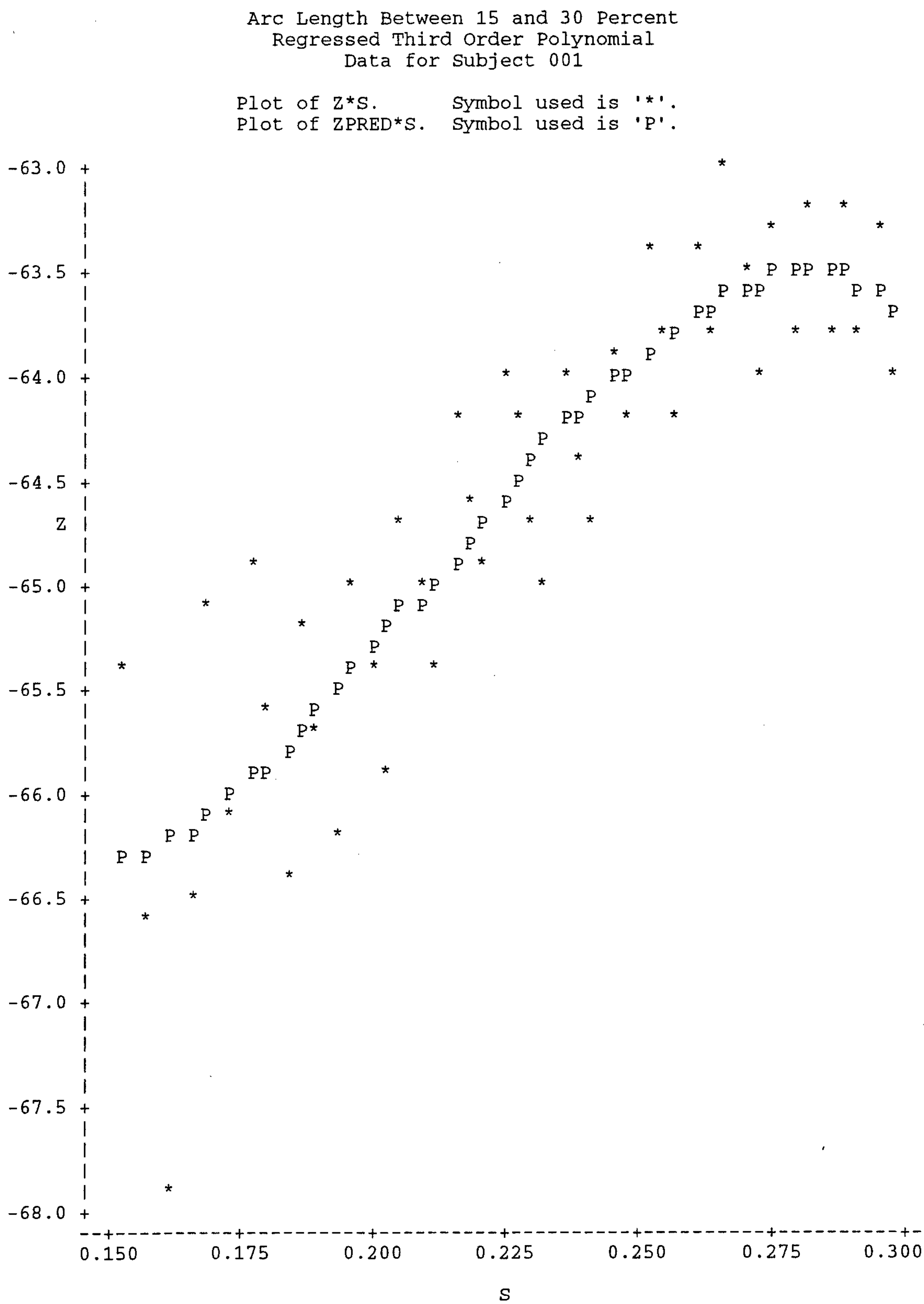


Figure J6. Arc Length Between 15 and 30 Percent for Z With Respect To S

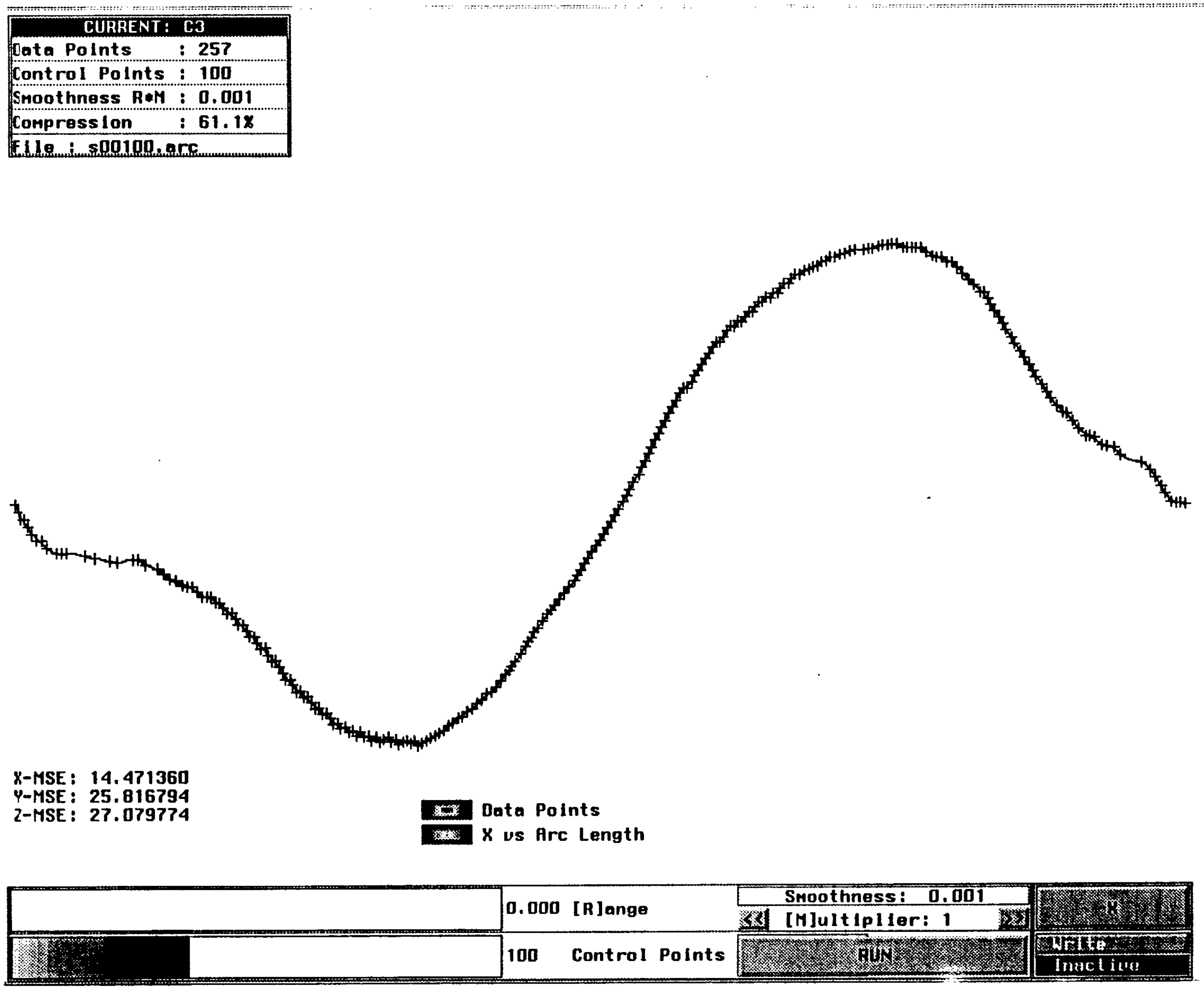


Figure J7. Quintic Spline Fit for X With Respect to S

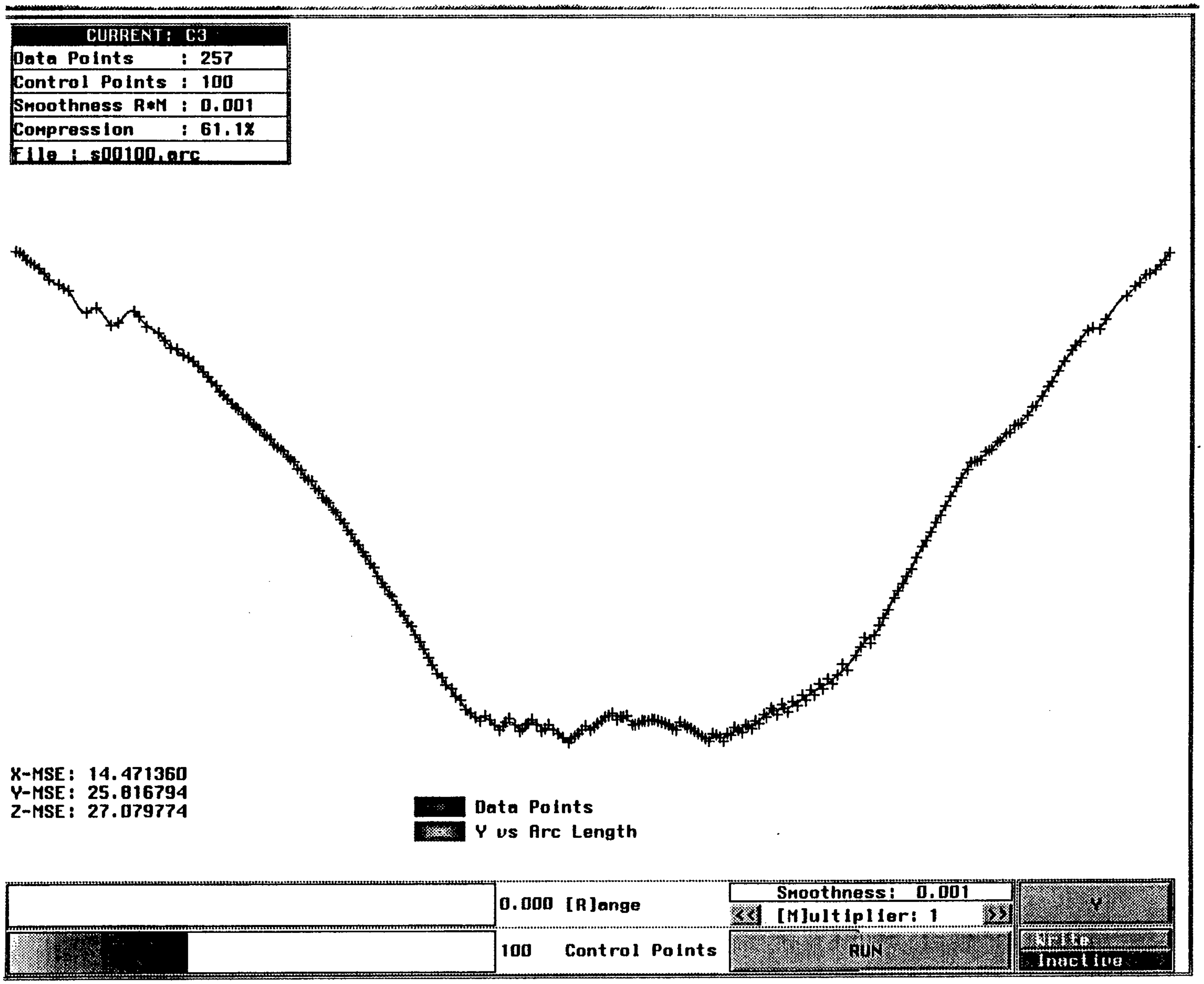


Figure J8. Quintic Spline Fit for Y With Respect to S

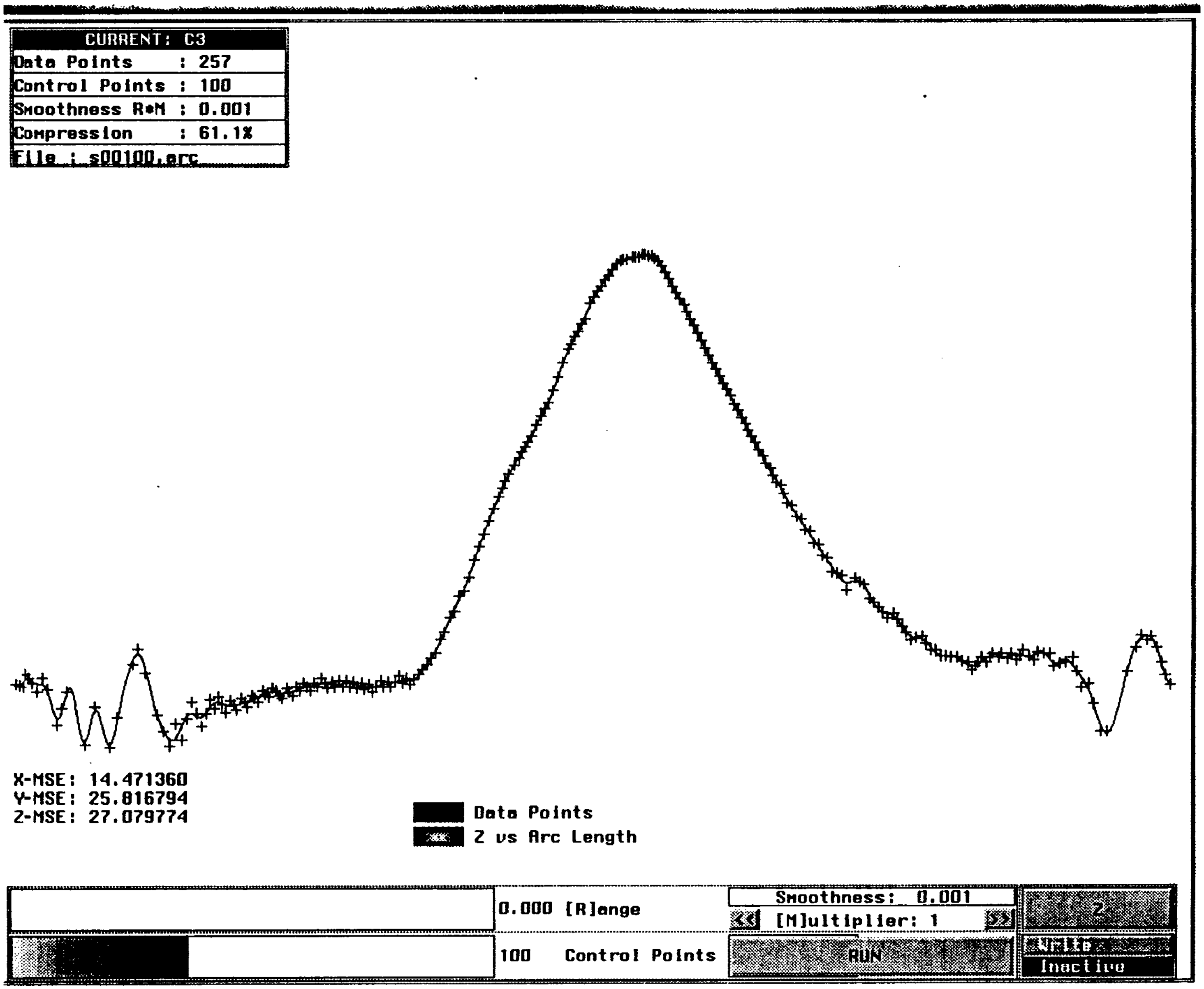


Figure J9. Quintic Spline Fit for Z With Respect to S

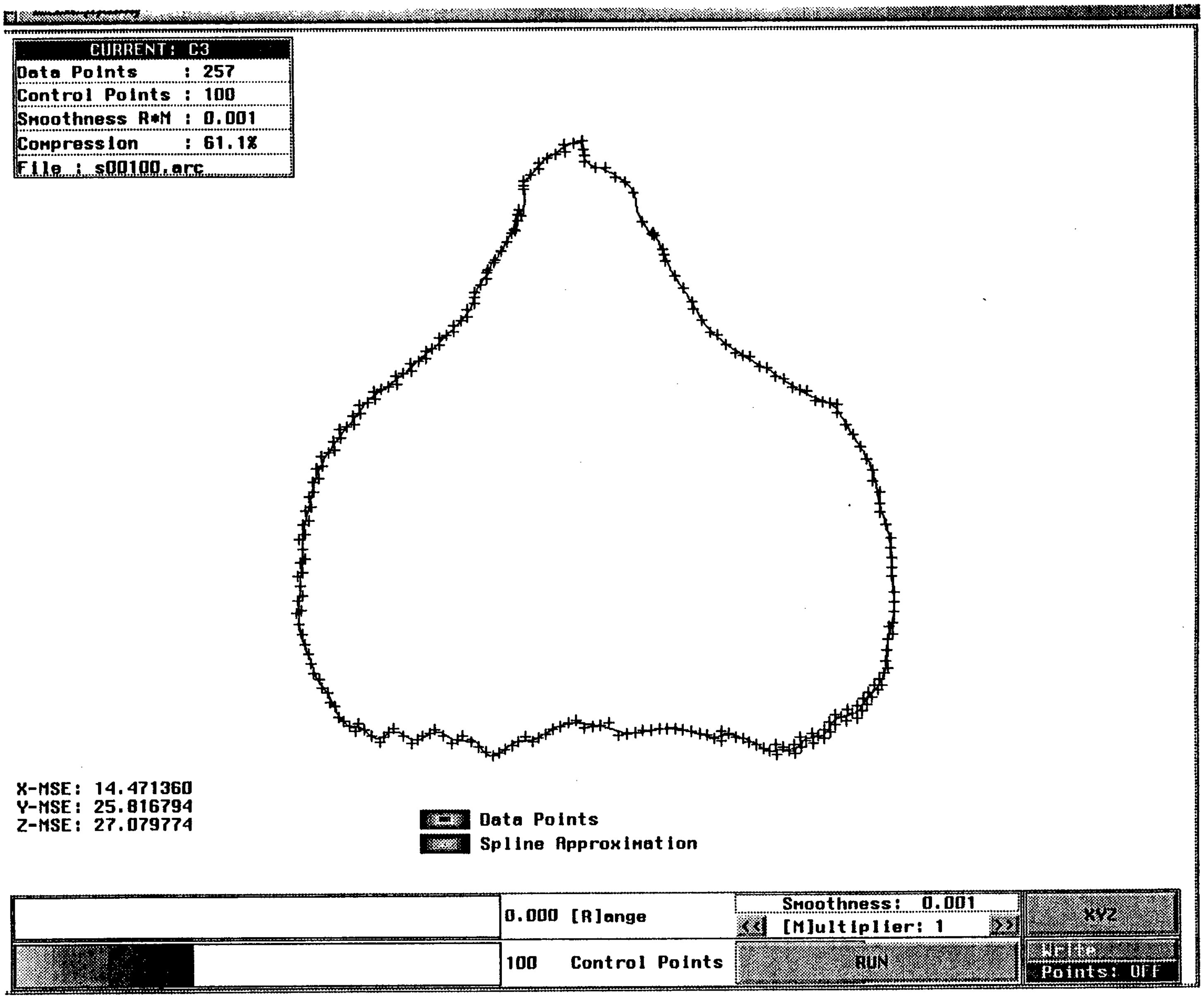


Figure J10. Quintic Spline Fit for X, Y, and Z With Respect to S

CRITICAL POINTS FOR SUBJECT 001

Plot of X*S. Symbol is value of SYMBOL.

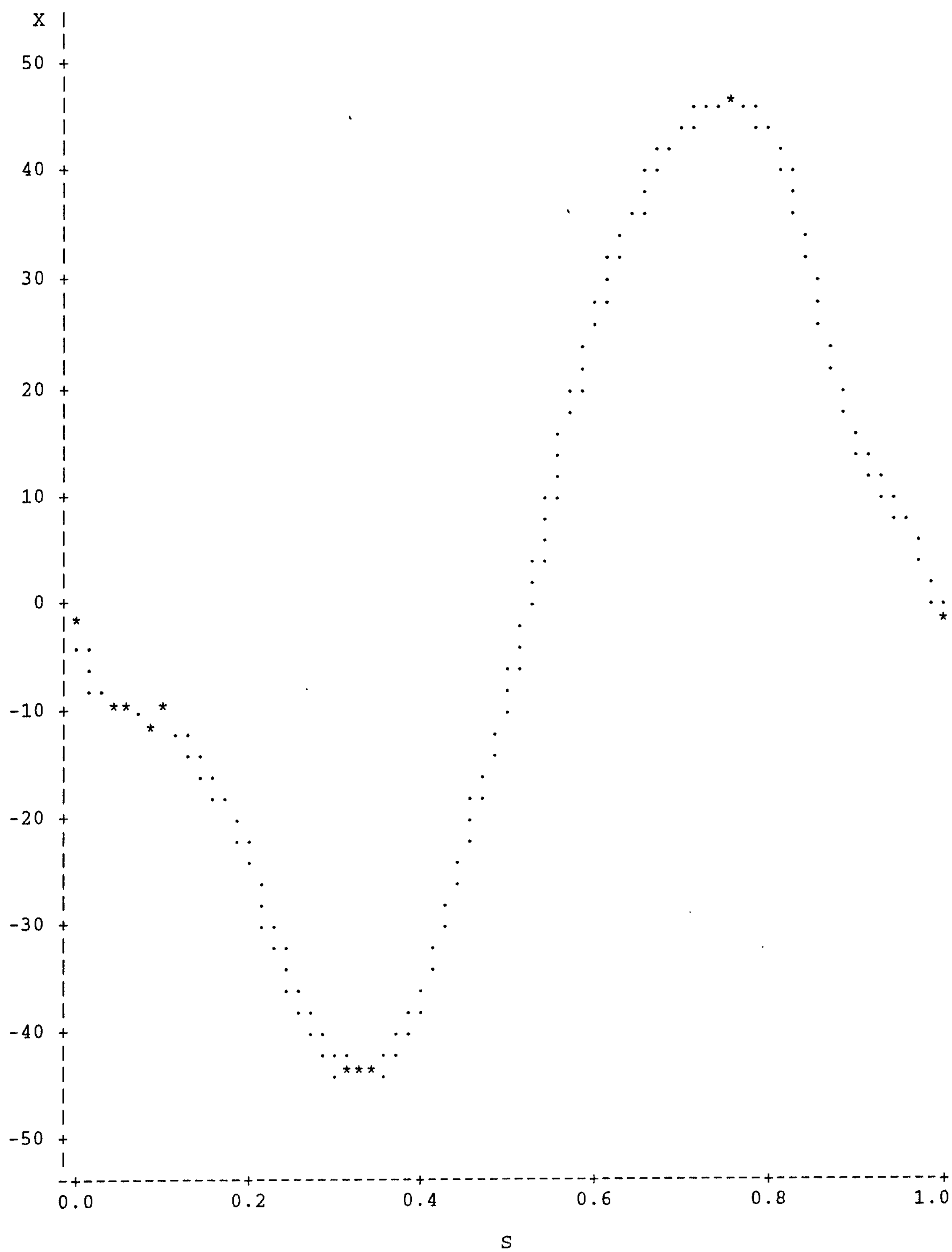


Figure J11. Critical Points for Subject 001

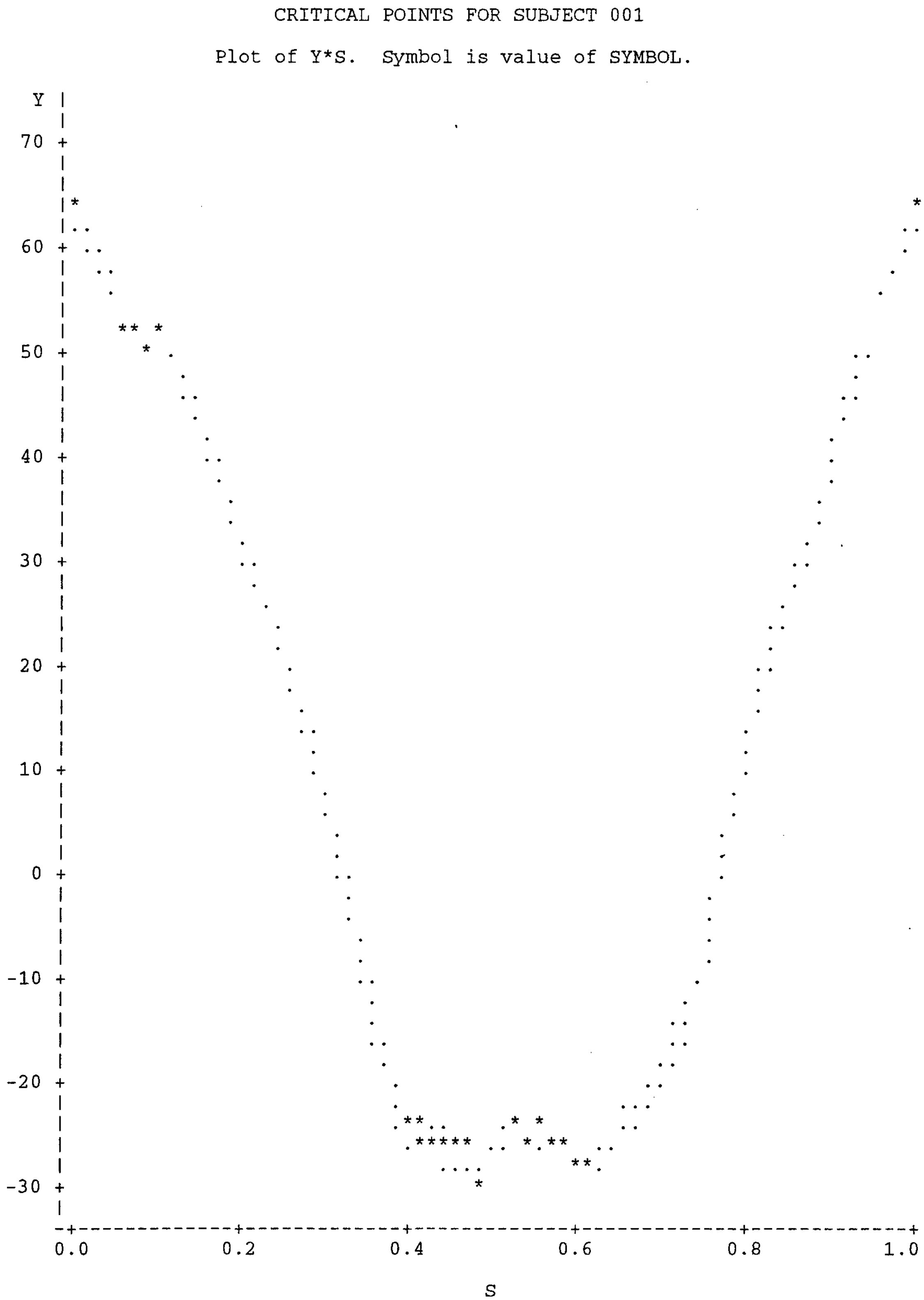


Figure J12. Critical Points for Subject 001

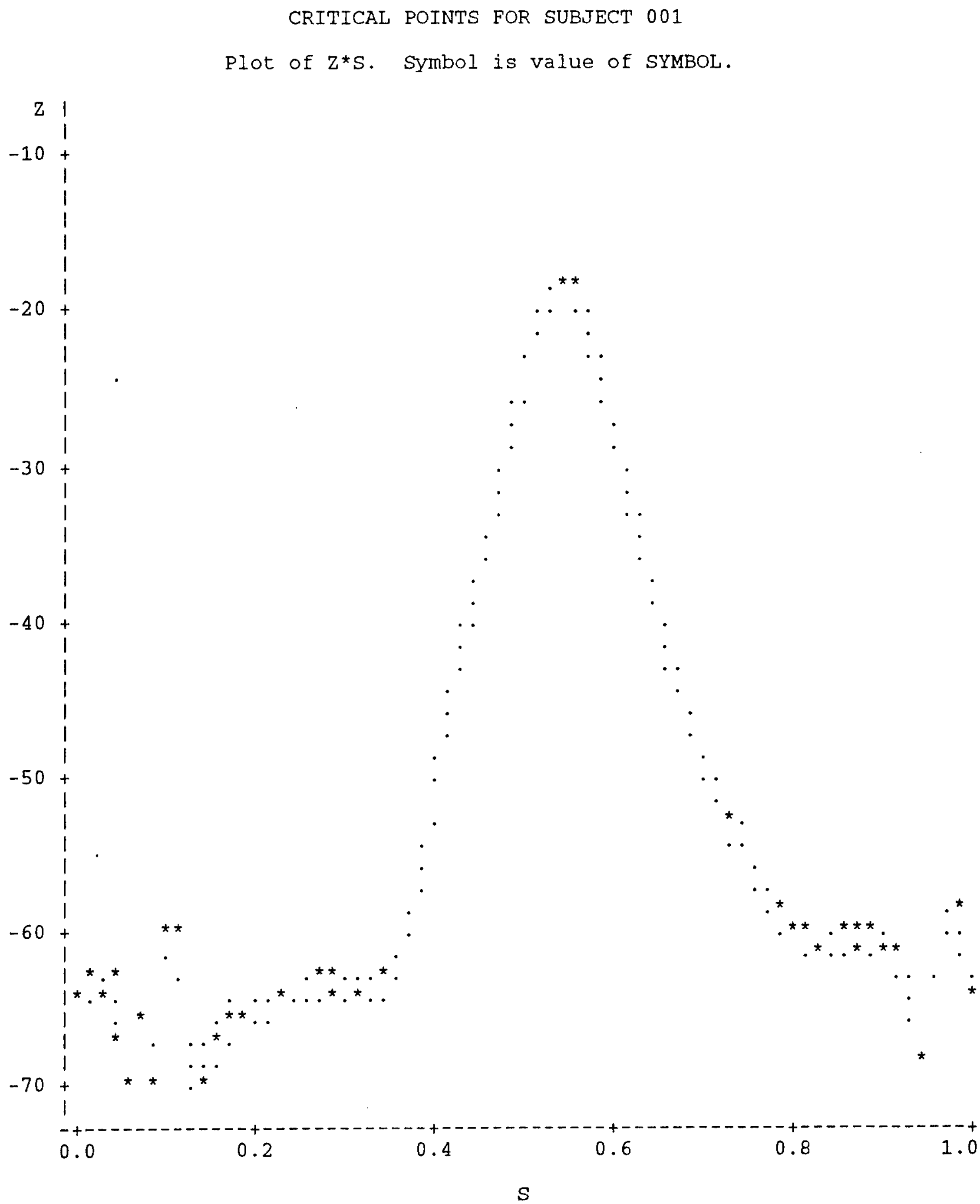


Figure J13. Critical Points for Subject 001

APPENDIX K

Summary Statistics

TABLE K1

Distribution of Subjects by Age

	MALE				FEMALE			
AGE	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
20	-	-	-	-	1	3.3	1	3.3
21	-	-	-	-	1	3.3	2	6.7
22	-	-	-	-	8	26.7	10	33.3
23	2	6.7	2	6.7	6	20.0	16	53.3
24	2	6.7	4	13.3	2	6.7	18	60.0
25	-	-	-	-	1	3.3	19	63.3
26	1	3.3	5	16.7	1	3.3	20	66.7
27	3	10.0	8	26.7	1	3.3	21	70.0
28	-	-	-	-	1	3.3	22	73.3
29	2	6.7	10	33.3	1	3.3	23	76.7
30	2	6.7	12	40.0	-	-	-	-
31	3	10.0	15	50.0	1	3.3	24	80.0
32	4	13.3	19	63.3	1	3.3	25	83.3
33	4	13.3	23	76.7	-	-	-	-
34	1	3.3	24	80.0	1	3.3	26	86.7
35	-	-	-	-	1	3.3	27	90.0
36	1	3.3	25	83.3	-	-	-	-
37	-	-	-	-	1	3.3	28	93.3
40	-	-	-	-	1	3.3	29	96.7
41	4	13.3	29	96.7	-	-	-	-
46	1	3.3	30	100.0	-	-	-	-
51	-	-	-	-	1	3.3	30	100.0

TABLE K2

Distribution of Subjects by Race

	MALE				FEMALE			
RACE	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
Asian/PI	1	3.3	1	3.3	2	6.7	2	6.7
Black	-	-	-	-	3	10.0	5	16.7
Hispanic	-	-	-	-	3	10.0	8	26.7
White	29	96.7	30	100.0	22	73.3	30	100.0

TABLE K3

Distribution of Subjects by Location

	MALE				FEMALE			
LOCATION	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
BROOKS	10	33.3	10	33.3	30	100.0	30	100.0
LUKE	20	66.7	30	100.0	-	-	-	-

TABLE K4

Distribution of Subjects by Major Command

	MALE				FEMALE			
MAJCOM	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
ACC	7	23.3	7	23.3	-	-	-	-
AETC	11	36.7	18	60.0	1	3.4	1	3.4
AFMC	9	30.0	27	90.0	25	86.2	26	89.7
AIA	1	3.3	28	93.3	-	-	-	-
AMC	-	-	-	-	1	3.4	27	93.1
AMFC	-	-	-	-	1	3.4	28	96.6
PACAF	-	-	-	-	1	3.4	29	100.0
USAFE	2	6.7	30	100.0	-	-	-	-

TABLE K5

Distribution of Subjects by Squadron

	MALE				FEMALE			
SQUADRON	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
12_AMS / S	-	-	-	-	1	3.3	1	3.3
302	4	13.3	4	13.3	-	-	-	-
308	4	13.3	8	26.7	-	-	-	-
310	3	10.0	11	36.7	-	-	-	-
315TH_AE	-	-	-	-	1	3.3	2	6.7
374_MED_	-	-	-	-	1	3.3	3	10.0
4	2	6.7	13	43.3	-	-	-	-
422	1	3.3	14	46.7	-	-	-	-
510	2	6.7	16	53.3	-	-	-	-
555	1	3.3	17	56.7	-	-	-	-
56	1	3.3	18	60.0	-	-	-	-
60TH_MED	-	-	-	-	1	3.3	4	13.3
63	2	6.7	20	66.7	-	-	-	-
70_CES	1	3.3	21	70.0	-	-	-	-
70_MDS / S	-	-	-	-	1	3.3	5	16.7
AFIWC	1	3.3	22	73.3	-	-	-	-
AL	-	-	-	-	3	10.0	8	26.7
AL / A0CO	-	-	-	-	1	3.3	9	30.0
AL / CFT	1	3.3	23	76.7	-	-	-	-
AL / CFTF	-	-	-	-	1	3.3	10	33.3
AL / CFTO	1	3.3	24	80.0	-	-	-	-
AL / CFTS	1	3.3	25	83.3	5	16.7	15	50.0
AL / D0JE	-	-	-	-	1	3.3	16	53.3
AL / HRMJ	-	-	-	-	1	3.3	17	56.7
AL / OEAO	1	3.3	26	86.7	-	-	-	-
AL / OEOP	1	3.3	27	90.0	-	-	-	-
DAO-DE / B	-	-	-	-	1	3.3	18	60.0
HSC	-	-	-	-	1	3.3	19	63.3
HSC / YA	1	3.3	28	93.3	1	3.3	20	66.7

	MALE				FEMALE			
SQUADRON	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
HSC / YAC	-	-	-	-	1	3.3	21	70.0
HSC / YAE	-	-	-	-	1	3.3	22	73.3
HSC / YAEC	-	-	-	-	1	3.3	23	76.7
HSC / YAT	-	-	-	-	1	3.3	24	80.0
SA-ALC	1	3.3	29	96.7	-	-	-	-
USAFSAM	-	-	-	-	1	3.3	25	83.3
USAFSAM/	1	3.3	30	100.0	5	16.7	30	100.0

Table K6. AAOM Males Summary Statistics for Anthropometry

VARIABLE	LABEL	N	MEAN	STD DEV	MINIMUM	MAXIMUM
X1	Head Circumference	30	577.30	15.49	541.00	610.00
X2	Bitragion-Subnasale Arc	30	289.27	13.87	262.00	325.00
X3	Head Length	30	202.03	6.47	187.00	216.00
X4	Head Breadth	30	154.30	4.18	144.00	164.00
X5	Bizygomatic Breadth	30	144.03	6.90	130.00	164.00
X6	Menton-Sellion Length	30	119.83	7.01	103.00	132.00
X7	Sellion-Supramenton Length	30	91.43	6.80	76.00	105.00
X8	Menton-Subnasale Length	30	70.00	5.83	55.00	80.00
X9	Bi-Inframalar Breadth	30	95.13	5.19	85.00	105.00
X10	Lip Length	30	52.13	2.86	47.00	58.00
X11	Lip Length, Smiling	30	61.43	4.38	52.00	70.00
X12	Nasal Root Breadth	30	16.87	2.36	13.00	21.00
X13	Nose Breadth	30	35.53	3.08	30.00	43.00
X14	Nose Length	30	51.17	3.92	42.00	60.00
X15	Nose Protrusion	30	17.37	2.40	13.00	23.00
X16	Head Circumference with Cap	30	587.90	15.16	550.00	617.00
X17	Head Length with Cap	30	208.43	7.07	194.00	222.00
X18	Head Breadth with Cap	30	160.57	4.26	149.00	171.00

Table K7. AAOM Females Summary Statistics for Anthropometry

VARIABLE	LABEL	N	MEAN	STD DEV	MINIMUM	MAXIMUM
X1	Head Circumference	30	549.07	12.59	526.00	573.00
X2	Bitragion-Subnasale Arc	30	269.60	11.54	252.00	307.00
X3	Head Length	30	188.93	6.21	177.00	202.00
X4	Head Breadth	30	146.80	5.50	136.00	158.00
X5	Bizygomatic Breadth	30	135.03	5.60	127.00	150.00
X6	Menton-Sellion Length	30	109.20	4.33	102.00	119.00
X7	Sellion-Supramenton Length	30	83.20	3.68	75.00	94.00
X8	Menton-Subnasale Length	30	63.80	3.85	57.00	72.00
X9	Bi-Inframalar Breadth	30	84.80	4.68	75.00	93.00
X10	Lip Length	30	46.97	3.37	41.00	55.00
X11	Lip Length, Smiling	30	56.60	4.55	48.00	66.00
X12	Nasal Root Breadth	30	15.67	1.49	12.00	18.00
X13	Nose Breadth	30	32.03	3.59	27.00	41.00
X14	Nose Length	30	45.70	3.15	40.00	52.00
X15	Nose Protrusion	30	13.57	2.36	8.00	17.00
X16	Head Circumference with Cap	30	564.47	10.10	548.00	585.00
X17	Head Length with Cap	30	196.97	4.72	188.00	207.00
X18	Head Breadth with Cap	30	156.33	6.29	146.00	171.00

APPENDIX L

Geometric Differences Between Mask Sizes

	SN to MN	SN to MW	SN to LW	MN to MW	MN to LW	MW to LW
Points	Ratio	Ratio	Ratio	Ratio	Ratio	Ratio
Top-Mid Mask to Bottom-Mid Mask	0.954	0.943	0.829	0.989	0.869	0.879
Top-Mid Mask to Min Right	1.351	0.967	0.948	0.716	0.702	0.981
Top-Mid Mask to Min Left	1.210	0.914	0.935	0.756	0.773	1.023
Top-Mid Mask to Max Right	1.003	0.980	0.904	0.977	0.901	0.922
Top-Mid Mask to Max Left	1.000	0.925	0.895	0.925	0.896	0.968
Top-Mid Mask to Max Bottom-Right	0.954	0.949	0.855	0.994	0.896	0.901
Top-Mid Mask to Max Bottom-Left	0.961	0.932	0.847	0.970	0.881	0.909
Bottom-Mid Mask to Min Right	0.934	0.971	0.839	1.040	0.898	0.864
Bottom-Mid Mask to Min Left	0.907	0.966	0.839	1.065	0.925	0.868
Bottom-Mid Mask to Max Right	1.002	0.992	0.903	0.990	0.901	0.911
Bottom-Mid Mask to Max Left	0.979	0.916	0.905	0.935	0.925	0.989
Bottom-Mid Mask to Max Bottom-Right	1.095	0.924	0.951	0.844	0.869	1.029
Bottom-Mid Mask to Max Bottom-Left	1.155	0.912	0.924	0.790	0.800	1.013
Min Right to Min Left	1.301	0.990	0.961	0.761	0.739	0.971
Min Right to Max Right	0.856	0.996	0.880	1.163	1.027	0.883
Min Right to Max Left	1.039	0.950	0.911	0.914	0.877	0.959
Min Right to Max Bottom-Right	0.840	0.960	0.820	1.144	0.977	0.854
Min Right to Max Bottom-Left	0.990	0.954	0.866	0.964	0.876	0.908
Min Left to Max Right	0.981	0.997	0.907	1.017	0.924	0.909
Min Left to Max Left	0.895	0.935	0.873	1.044	0.975	0.934
Min Left to Max Bottom-Right	0.939	0.958	0.872	1.020	0.930	0.911
Min Left to Max Bottom-Left	0.860	0.950	0.816	1.105	0.949	0.859
Max Right to Max Left	1.002	0.966	0.904	0.964	0.902	0.936
Max Right to Max Bottom-Right	0.770	1.015	0.738	1.318	0.958	0.727
Max Right to Max Bottom-Left	1.030	0.966	0.894	0.938	0.868	0.926
Max Left to Max Bottom-Right	1.015	0.929	0.916	0.915	0.903	0.987
Max Left to Max Bottom-Left	0.714	0.933	0.755	1.308	1.057	0.809
Max Bottom-Right to Max Bottom-Left	1.103	0.925	0.933	0.839	0.846	1.008

Comparing Mask Size SN to Mask Size MN

The distances from Top-Mid Mask to Min Right and Min Right to Min Left are 20% to 29% larger for SN than for MN.

The distances from Top-Mid Mask to Min Left and Bottom-Mid Mask to Max Bottom-Left are both 10% to 19% larger for SN than for MN.

The distances from Bottom-Mid Mask to Max Bottom-Right, Min Right to Max Left, Max Right to Max Bottom-Left, Max Left to Max Bottom-Right and Max Bottom-Right to Max Bottom-Left are all 1% to 9% larger for SN than MN.

The distances from Top-Mid Mask to Max Right, Top-Mid Mask to Max Left, Bottom-Mid Mask to Max Right, Min Right to Max Bottom-Left and Max Right to Max Left are virtually unchanged from SN to MN.

All of the following distances were 1%-9% smaller for SN than for MN: Top-Mid Mask to Bottom-Mid Mask, Top-Mid Mask to Max Bottom-Right, Top-Mid Mask to Max Bottom-Left, Bottom-Mid Mask to Min Right, Bottom-Mid Mask to Min Left, Bottom-Mid Mask to Max Left, Min Left to Max Right and Min Left to Max Bottom-Right.

The distances from Min Right to Max Right, Min Right to Max Bottom-Right, Min Left to Max Left and Min Left to Max Bottom-Left are 10% to 19% smaller for SN than for MN.

The distances from Max Left to Max Bottom-Left and Max Right to Max Bottom-Right are 20% to 29% smaller for SN than for MN.

Comparing Mask Size SN to Mask Size MW

The distances from Bottom-Mid Mask to Max Right, Min Right to Min Left, Min Right to Max Right, Min Left to Max Right and Max Right to Max Bottom-Right are virtually equal between the SN and MW masks.

All other distances were between 1% to 9% smaller for SN than for MW.

Comparing Mask Size SN to Mask Size LW

The distances from Max Right to Max Bottom-Right and Max Left to Max Bottom-Left are 20% to 29% smaller for SN than LW.

All of the following distances are 10% to 19% smaller for SN than LW: Top-Mid Mask to Bottom-Mid Mask, Top-Mid Mask to Max Right, Top-Mid Mask to Max Left, Top-Mid Mask to Max Bottom-Right, Top-Mid Mask to Max Bottom-Left, Bottom-Mid Mask to Min Right, Bottom-Mid Mask to Min Left, Bottom-Mid Mask to Max Right, Bottom-Mid Mask to Max Left, Min Right to Max Right, Min Right to Max Bottom-Right, Min Right to Max Bottom-Left, Min Left to Max Left, Min Left to Max Bottom-Right, Min Left to Max Bottom-Left and Max Right to Max Bottom-Left.

The distances from Top-Mid Mask to Min Right, Top-Mid Mask to Min Left, Bottom-Mid Mask to Max Bottom-Right, Bottom-Mid Mask to Max Bottom-Left, Min Right to Min Left, Min Right to Max Left, Min Left to Max Right, Max Right to Max Left, Max Left to Max Bottom-Right and Max Bottom-Right to Max Bottom-Left are all 1% to 9% smaller for SN than for LW.

Comparing Mask Size MN to Mask Size MW

The distances from Max Right to Max Bottom-Right and Max Left to Max Bottom-Left are 20% to 29% larger for MN than for MW.

The distances from Min Right to Max Right, Min Right to Max Bottom-Right and Min Left to Max Bottom-Left are 10% to 19% larger for MN than for MW.

The distances from Bottom-Mid Mask to Min Right, Bottom-Mid Mask to Min Left, Min Left to Max Right, Min Left to Max Left and Min Left to Max Bottom-Right are 1% to 9% larger for MN than for MW.

The distances from Top-Mid Mask to Bottom-Mid Mask, Top-Mid Mask to Max Bottom-Right and Bottom-Mid Mask to Max Right are virtually unchanged from MN to MW.

All of the following distances are 1% to 9% smaller for MN than for MW: Top-Mid Mask to Max Right, Top-Mid Mask to Max Left, Top-Mid Mask to Max Bottom-Left, Bottom-Mid Mask to Max Left, Min Right to Max Left, Min Right to Max Bottom-Left, Max Right to Max Left, Max Right to Max Bottom-Left and Max Left to Max Bottom-Right.

The distances from Bottom-Mid Mask to Max Bottom-Right and Max Bottom-Right to Max Bottom-Left are 10% to 19% smaller for MN than for MW.

The distances from Top-Mid Mask to Min Right, Top-Mid Mask to Min Left, Bottom-Mid Mask to Max Bottom-Left and Min Right to Min Left are 20% to 29% smaller for MN than for MW.

Comparing Mask Size MN to Mask Size LW

The distances from Min Right to Max Right and Max Left to Max Bottom-Left are 1% to 9% larger for the MN than the LW.

The distances from Bottom-Mid Mask to Min Left, Bottom-Mid Mask to Max Left, Min Right to Max Bottom-Right, Min Left to Max Right, Min Left to Max Left, Min Left to Max Bottom-Right, Min Left to Max Bottom-Left and Max Right to Max Bottom-Right are 1% to 9% smaller for the MN than the LW.

All of the following distances are 10% to 19% smaller for MN than for LW: Top-Mid Mask to Bottom-Mid Mask, Top-Mid Mask to Max Right, Top-Mid Mask to Max Left, Top-Mid Mask to Max Bottom-Right, Top-Mid Mask to Max Bottom-Left, Bottom-Mid Mask to Min Right, Bottom-Mid Mask to Max Right, Bottom-Mid Mask to Max Bottom-Right, Min Right to Max Left, Min Right to Max Bottom-Left, Max Right to Max Left, Max Right to Max Bottom-Left, Max Left to Max Bottom-Right and Max Bottom-Right to Max Bottom-Left.

The distances from Top-Mid Mask to Min Right, Top-Mid Mask to Min Left, Bottom-Mid Mask to Max Bottom-Left and Min Right to Min Left are 20% to 29% smaller for MN than for LW.

Comparing Mask Size MW to Mask Size LW

The distances from Top-Mid Mask to Min Left and Bottom-Mid Mask to Max Bottom-Right are 1% to 9% larger for MW than for LW.

The distances from Bottom-Mid Mask to Max Left, Bottom-Mid Mask to Max Bottom-Left, Min Right to Max Bottom-Left, Max Left to Max Bottom-Right and Max Bottom-Right to Max Bottom-Left are virtually equal for MW and LW.

All of the following distances are 1% to 9% smaller for MW than for LW: Top-Mid Mask to Min Right, Top-Mid Mask to Max Right, Top-Mid Mask to Max Left, Bottom-Mid Mask to Max Right, Min Right to Min Left, Min Right to Max Left, Min Left to Max Right, Min Left to Max Left, Min Left to Max Bottom-Right, Max Right to Max Left and Max Right to Max Bottom-Left.

The distances from Top-Mid Mask to Bottom-Mid Mask, Top-Mid Mask to Max Bottom-Right, Top-Mid Mask to Max Bottom-Left, Bottom-Mid Mask to Min Right, Bottom-Mid Mask to Min Left, Min Right to Max Right, Min Right to Max Bottom-Right, Min Left to Max Bottom-Left and Max Left to Max Bottom-Left are 10% to 19% smaller for MW than for LW.

The distance from Max Right to Max Bottom-Right is 27% smaller for MW than for LW.

APPENDIX M

MANOVA Results

Number of observations in data set = 30

EFFECT OF OVERALL SCORE ON ANTHROPOMETRY

First Eigenvalue and Eigenvector of: E Inverse * H, where
H = Type IV SS&CP Matrix for OVERSCOR   E = Error SS&CP Matrix

First Eigenvalue: 3.99573223   Percent: 100.00
First Eigenvector:

-0.05170103	(Head Circ)	0.04342454	(Bitrag-Subnas Arc)
0.09387026	(Head Lgth)	0.07301938	(Head Brdth)
-0.04487768	(Bizygomatic Brdth)	-0.24986929	(Menton-Sellion Lgth)
-0.07465381	(Sellion-Supramen Lgth)	0.24352762	(Menton-Subnas Lgth)
-0.03496679	(Bi-Inframalar Brdth)	-0.10680411	(Lip Lgth)
0.03253172	(Lip Length, Smiling)	-0.07264582	(Nasal Root Brdth)
0.01712725	(Nose Brdth)	0.24664128	(Nose Lgth)
0.02557778	(Nose Protrusion)		

MANOVA Test Criteria and Exact F Statistics for the Hypothesis of no Overall OVERSCOR Effect

H = Type IV SS&CP Matrix for OVERSCOR   E = Error SS&CP Matrix

Statistic	Value	F	Num DF	Den DF	Pr > F
Wilks' Lambda	0.20017086	2.1311	15	8	0.1408
Pillai's Trace	0.79982914	2.1311	15	8	0.1408

EFFECT OF MASK SIZE ON ANTHROPOMETRY

First Eigenvalue and Eigenvector of: E Inverse * H, where
H = Type IV SS&CP Matrix for MASKSIZE   E = Error SS&CP Matrix

First Eigenvalue: 5.97239719   Percent: 75.06
First Eigenvector:

0.02153208	(Head Circ)	-0.03919924	(Bitrag-Subnas Arc)
-0.01611211	(Head Lgth)	-0.08804791	(Head Brdth)
0.06951354	(Bizygomatic Brdth)	0.04372398	(Menton-Sellion Lgth)
0.11068576	(Sellion-Supramen Lgth)	-0.08943938	(Menton-Subnas Lgth)
0.00288984	(Bi-Inframalar Brdth)	0.00202404	(Lip Lgth)
0.04251684	(Lip Length, Smiling)	0.09266388	(Nasal Root Brdth)
-0.03779790	(Nose Brdth)	-0.00562494	(Nose Lgth)
-0.09186018	(Nose Protrusion)		

Second Eigenvalue and Eigenvector of: E Inverse * H, where
H = Type IV SS&CP Matrix for MASKSIZE   E = Error SS&CP Matrix

Second Eigenvalue: 1.16782262   Percent: 14.68
Second Eigenvector:

-0.01476963	(Head Circ)	-0.01148960	(Bitrag-Subnas Arc)
0.04874257	(Head Lgth)	0.03483104	(Head Brdth)
0.02303829	(Bizygomatic Brdth)	-0.17294844	(Menton-Sellion Lgth)
0.00379557	(Sellion-Supramen Lgth)	0.14629609	(Menton-Subnas Lgth)
0.00279746	(Bi-Inframalar Brdth)	0.02249534	(Lip Lgth)
0.00179198	(Lip Length, Smiling)	-0.00372012	(Nasal Root Brdth)
-0.00600263	(Nose Brdth)	0.14029082	(Nose Lgth)
0.04793966	(Nose Protrusion)		

MANOVA Test Criteria and F Approximations for the Hypothesis of no Overall MASKSIZE Effect

H = Type IV SS&CP Matrix for MASKSIZE   E = Error SS&CP Matrix

Statistic	Value	F	Num DF	Den DF	Pr > F
Wilks' Lambda	0.03641446	1.1182	45	24.54655	0.3913
Pillai's Trace	1.84488334	1.0648	45	30	0.4348

EFFECT OF THE INTERACTION BETWEEN OVERALL SCORE AND MASK SIZE

First Eigenvalue and Eigenvector of: E Inverse * H, where
H = Type IV SS&CP Matrix for OVERSCOR*MASKSIZE   E = Error SS&CP Matrix

First Eigenvalue: 6.58415176   Percent: 73.84
First Eigenvector:

0.04490502	(Head Circ)	-0.03369820	(Bitrag-Subnas Arc)
-0.09025023	(Head Lgth)	-0.07139293	(Head Brdth)
0.01933111	(Bizygomatic Brdth)	0.31621325	(Menton-Sellion Lgth)
0.06972797	(Sellion-Supramen Lgth)	-0.28898410	(Menton-Subnas Lgth)
0.05824376	(Bi-Inframalar Brdth)	0.10370966	(Lip Lgth)
-0.04677466	(Lip Length, Smiling)	0.02856003	(Nasal Root Brdth)
-0.00903477	(Nose Brdth)	-0.30847226	(Nose Lgth)
-0.02124633	(Nose Protrusion)		

Second Eigenvalue and Eigenvector of: E Inverse * H, where
H = Type IV SS&CP Matrix for OVERSCOR*MASKSIZE   E = Error SS&CP Matrix

Second Eigenvalue: 1.67400766   Percent: 18.77
Second Eigenvector:

-0.03606456	(Head Circ)	0.01761828	(Bitrag-Subnas Arc)
0.06604050	(Head Lgth)	0.02363510	(Head Brdth)
-0.02925153	(Bizygomatic Brdth)	0.00574537	(Menton-Sellion Lgth)
0.01006186	(Sellion-Supramen Lgth)	-0.00788481	(Menton-Subnas Lgth)
0.01694493	(Bi-Inframalar Brdth)	-0.00837683	(Lip Lgth)
0.00952489	(Lip Length, Smiling)	-0.11252173	(Nasal Root Brdth)
0.00743365	(Nose Brdth)	-0.01122194	(Nose Lgth)
0.03930540	(Nose Protrusion)		

MANOVA Test Criteria and F Approximations for the Hypothesis of no Overall OVERSCOR*MASKSIZE Effect

H = Type IV SS&CP Matrix for OVERSCOR*MASKSIZE   E = Error SS&CP Matrix

Statistic	Value	F	Num DF	Den DF	Pr > F
Wilks' Lambda	0.02973412	1.2357	45	24.54655	0.2910
Pillai's Trace	1.89116534	1.1370	45	30	0.3600

APPENDIX N

ANOVA Results

ANOVA RESULTS

Dependent Variable: X1 Head Circumference

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	1501.83571	214.54796	0.87	0.5480
Error	22	5452.46429	247.83929		
Corrected Total	29	6954.30000			

R-Square	C.V.	Root MSE	X1 Mean
0.215958	2.726990	15.7429	577.300

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	184.80267	184.80267	0.75	0.3972
MASKSIZE	3	1305.71076	435.23692	1.76	0.1850
OVERSCOR*MASKSIZE	3	86.95727	28.98576	0.12	0.9492

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X1 HEAD CIRCUMFERENCE

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
PASS - FAIL	-7.770	4.179	16.127
FAIL - PASS	-16.127	-4.179	7.770

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
LW - MW	-25.479	9.571	44.622
LW - SN	-17.513	16.091	49.695
LW - MN	-11.162	22.700	56.562
MW - LW	-44.622	-9.571	25.479
MW - SN	-14.617	6.519	27.656
MW - MN	-8.415	13.129	34.672
SN - LW	-49.695	-16.091	17.513
SN - MW	-27.656	-6.519	14.617
SN - MN	12.492	6.609	25.710
MN - LW	-56.562	-22.700	11.162
MN - MW	-34.672	-13.129	8.415
MN - SN	-25.710	-6.609	12.492

Dependent Variable: X2 Bitragion-Subnasale Arc

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	1151.98571	164.56939	0.82	0.5828
Error	22	4427.88095	201.26732		
Corrected Total	29	5579.86667			

R-Square	C.V.	Root MSE	X2 Mean
0.206454	4.904427	14.1869	289.267

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	6.933011	6.933011	0.03	0.8545
MASKSIZE	3	426.295076	142.098359	0.71	0.5586
OVERSCOR*MASKSIZE	3	684.792751	228.264250	1.13	0.3570

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X2 BITRAGION-SUBNASALE ARC

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
FAIL - PASS	-8.990	1.777	12.544
PASS - FAIL	-12.544	-1.777	8.990

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
LW - MW	-31.443	0.143	31.729
LW - MN	-24.115	6.400	36.915
LW - SN	-20.556	9.727	40.010
MW - LW	-31.729	-0.143	31.443
MW - MN	-13.157	6.257	25.671
MW - SN	-9.463	9.584	28.631
MN - LW	-36.915	-6.400	24.115
MN - MW	-25.671	-6.257	13.157
MN - SN	-13.885	3.327	20.540
SN - LW	-40.010	-9.727	20.556
SN - MW	-28.631	-9.584	9.463
SN - MN	-20.540	-3.327	13.885

Dependent Variable: X3 Head Length

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	154.502381	22.071769	0.46	0.8541
Error	22	1060.464286	48.202922		
Corrected Total	29	1214.966667			

R-Square	C.V.	Root MSE	X3 Mean
0.127166	3.436479	6.94283	202.033

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	8.705637	8.705637	0.18	0.6750
MASKSIZE	3	106.622297	35.540766	0.74	0.5410
OVERSCOR*MASKSIZE	3	35.314963	11.771654	0.24	0.8645

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X3 HEAD LENGTH

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
FAIL - PASS	-4.3943	0.8750	6.1443
PASS - FAIL	-6.1443	-0.8750	4.3943

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
LW - MW	-12.743	2.714	18.172
LW - SN	-8.820	6.000	20.820
LW - MN	-8.534	6.400	21.334
MW - LW	-18.172	-2.714	12.743
MW - SN	-6.036	3.286	12.607
MW - MN	-5.815	3.686	13.187
SN - LW	-20.820	-6.000	8.820
SN - MW	-12.607	-3.286	6.036
SN - MN	-8.024	0.400	8.824
MN - LW	-21.334	-6.400	8.534
MN - MW	-13.187	-3.686	5.815
MN - SN	-8.824	-0.400	8.024

Dependent Variable: X4 Head Breadth

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	179.600000	25.657143	1.73	0.1542
Error	22	326.700000	14.850000		
Corrected Total	29	506.300000			

R-Square	C.V.	Root MSE	X4 Mean
0.354730	2.497453	3.85357	154.300

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	111.474753	111.474753	7.51	0.0120
MASKSIZE	3	40.252862	13.417621	0.90	0.4553
OVERSCOR*MASKSIZE	3	81.512254	27.170751	1.83	0.1712

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X4 HEAD BREADTH

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
PASS - FAIL	-0.085	2.839	5.764
FAIL - PASS	-5.764	-2.839	0.085

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
LW - SN	-7.226	1.000	9.226
LW - MW	-7.580	1.000	9.580
LW - MN	-4.989	3.300	11.589
SN - LW	-9.226	-1.000	7.226
SN - MW	-5.174	0.000	5.174
SN - MN	-2.375	2.300	6.975
MW - LW	-9.580	-1.000	7.580
MW - SN	-5.174	0.000	5.174
MW - MN	-2.973	2.300	7.573
MN - LW	-11.589	-3.300	4.989
MN - SN	-6.975	-2.300	2.375
MN - MW	-7.573	-2.300	2.973

Dependent Variable: X5   Bizygomatic Breadth

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	460.788095	65.826871	1.57	0.1954
Error	22	920.178571	41.826299		
Corrected Total	29	1380.966667			

R-Square	C.V.	Root MSE	X5 Mean
0.333671	4.490159	6.46733	144.033

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	174.384581	174.384581	4.17	0.0533
MASKSIZE	3	154.708459	51.569486	1.23	0.3215
OVERSCOR*MASKSIZE	3	258.166062	86.055354	2.06	0.1351

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X5   BIZYGOMATIC BREADTH

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
PASS - FAIL	-2.435	2.473	7.382
FAIL - PASS	-7.382	-2.473	2.435

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
LW - MW	-12.756	1.643	16.042
LW - MN	-8.211	5.700	19.611
LW - SN	-7.850	5.955	19.760
MW - LW	-16.042	-1.643	12.756
MW - MN	-4.793	4.057	12.907
MW - SN	-4.371	4.312	12.995
MN - LW	-19.611	-5.700	8.211
MN - MW	-12.907	-4.057	4.793
MN - SN	-7.592	0.255	8.101
SN - LW	-19.760	-5.955	7.850
SN - MW	-12.995	-4.312	4.371
SN - MN	-8.101	-0.255	7.592

Dependent Variable: X6 Menton-Sellion Length

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	817.252381	116.750340	4.22	0.0043
Error	22	608.914286	27.677922		
Corrected Total	29	1426.166667			

R-Square	C.V.	Root MSE	X6 Mean
0.573041	4.390248	5.26098	119.833

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	13.811243	13.811243	0.50	0.4874
MASKSIZE	3	614.661117	204.887039	7.40	0.0013
OVERSCOR*MASKSIZE	3	105.312280	35.104093	1.27	0.3097

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X6 MENTON-SELLION LENGTH

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
FAIL - PASS	-1.136	2.857	6.850
PASS - FAIL	-6.850	-2.857	1.136

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
LW - MW	-3.999	7.714	19.427	
LW - MN	-1.616	9.700	21.016	
LW - SN	5.497	16.727	27.957	***
MW - LW	-19.427	-7.714	3.999	
MW - MN	-5.214	1.986	9.185	
MW - SN	1.950	9.013	16.076	***
MN - LW	-21.016	-9.700	1.616	
MN - MW	-9.185	-1.986	5.214	
MN - SN	0.644	7.027	13.410	***
SN - LW	-27.957	-16.727	-5.497	***
SN - MW	-16.076	-9.013	-1.950	***
SN - MN	-13.410	-7.027	-0.644	***

Dependent Variable: X7 Sellion-Supramenton Length

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	869.242857	124.177551	5.81	0.0007
Error	22	470.123810	21.369264		
Corrected Total	29	1339.366667			

	R-Square	C.V.	Root MSE	X7 Mean
	0.648995	5.055804	4.62269	91.4333

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	8.349956	8.349956	0.39	0.5383
MASKSIZE	3	744.073418	248.024473	11.61	0.0001
OVERSCOR*MASKSIZE	3	82.024044	27.341348	1.28	0.3060

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X7 SELLION-SUPRAMENTON LENGTH

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
FAIL - PASS	-1.375	2.134	5.642
PASS - FAIL	-5.642	-2.134	1.375

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
LW - MW	0.065	10.357	20.649	***
LW - MN	1.357	11.300	21.243	***
LW - SN	8.905	18.773	28.640	***
MW - LW	-20.649	-10.357	-0.065	***
MW - MN	-5.383	0.943	7.269	
MW - SN	2.209	8.416	14.622	***
MN - LW	-21.243	-11.300	-1.357	***
MN - MW	-7.269	-0.943	5.383	
MN - SN	1.864	7.473	13.081	***
SN - LW	-28.640	-18.773	-8.905	***
SN - MW	-14.622	-8.416	-2.209	***
SN - MN	-13.081	-7.473	-1.864	***

Dependent Variable: X8 Menton-Subnasale Length

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	381.650000	54.521429	1.98	0.1037
Error	22	604.350000	27.470455		
Corrected Total	29	986.000000			

	R-Square	C.V.	Root MSE	X8 Mean
	0.387069	7.487466	5.24123	70.0000

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	25.342913	25.342913	0.92	0.3472
MASKSIZE	3	309.657156	103.219052	3.76	0.0256
OVERSCOR*MASKSIZE	3	10.987030	3.662343	0.13	0.9392

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X8 MENTON-SUBNASALE LENGTH

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
FAIL - PASS	-1.031	2.946	6.924
PASS - FAIL	-6.924	-2.946	1.031

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
LW - MW	-4.098	7.571	19.241	
LW - MN	-3.474	7.800	19.074	
LW - SN	1.449	12.636	23.824	***
MW - LW	-19.241	-7.571	4.098	
MW - MN	-6.944	0.229	7.401	
MW - SN	-1.972	5.065	12.102	
MN - LW	-19.074	-7.800	3.474	
MN - MW	-7.401	-0.229	6.944	
MN - SN	-1.523	4.836	11.195	
SN - LW	-23.824	-12.636	-1.449	***
SN - MW	-12.102	-5.065	1.972	
SN - MN	-11.195	-4.836	1.523	

Dependent Variable: X9 Bi-Inframalar Breadth

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	188.400000	26.914286	1.00	0.4584
Error	22	593.066667	26.957576		
Corrected Total	29	781.466667			

R-Square	C.V.	Root MSE	X9 Mean
0.241085	5.457675	5.19207	95.1333

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	15.928538	15.928538	0.59	0.4503
MASKSIZE	3	80.822868	26.940956	1.00	0.4117
OVERSCOR*MASKSIZE	3	117.147734	39.049245	1.45	0.2558

Tukey's Studentized Range (HSD) Test for variable: X9 Bi-Inframalar Breadth

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
PASS - FAIL	-3.8245	0.1161	4.0566
FAIL - PASS	-4.0566	-0.1161	3.8245

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
LW - SN	-6.901	4.182	15.265
LW - MW	-5.988	5.571	17.131
LW - MN	-5.068	6.100	17.268
SN - LW	-15.265	-4.182	6.901
SN - MW	-5.581	1.390	8.360
SN - MN	-4.381	1.918	8.218
MW - LW	-17.131	-5.571	5.988
MW - SN	-8.360	-1.390	5.581
MW - MN	-6.576	0.529	7.634
MN - LW	-17.268	-6.100	5.068
MN - SN	-8.218	-1.918	4.381
MN - MW	-7.634	-0.529	6.576

Dependent Variable: X10 Lip Length

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	72.1428571	10.3061224	1.37	0.2661
Error	22	165.3238095	7.5147186		
Corrected Total	29	237.4666667			

R-Square	C.V.	Root MSE	X10 Mean
0.303802	5.258246	2.74130	52.1333

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	16.6185036	16.6185036	2.21	0.1512
MASKSIZE	3	39.0515930	13.0171977	1.73	0.1896
OVERSCOR*MASKSIZE	3	18.3825411	6.1275137	0.82	0.4991

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X10 LIP LENGTH

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
PASS - FAIL	-0.6252	1.4554	3.5359
FAIL - PASS	-3.5359	-1.4554	0.6252

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
SN - MW	-1.382	2.299	5.979
SN - MN	-0.699	2.627	5.953
SN - LW	-3.124	2.727	8.579
MW - SN	-5.979	-2.299	1.382
MW - MN	-3.423	0.329	4.080
MW - LW	-5.675	0.429	6.532
MN - SN	-5.953	-2.627	0.699
MN - MW	-4.080	-0.329	3.423
MN - LW	-5.796	0.100	5.996
LW - SN	-8.579	-2.727	3.124
LW - MW	-6.532	-0.429	5.675
LW - MN	-5.996	-0.100	5.796

Dependent Variable: X11 Lip Length, Smiling

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	95.3880952	13.6268707	0.65	0.7092
Error	22	459.9785714	20.9081169		
Corrected Total	29	555.3666667			

R-Square	C.V.	Root MSE	X11 Mean
0.171757	7.443092	4.57254	61.4333

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	56.6991084	56.6991084	2.71	0.1138
MASKSIZE	3	3.1016611	1.0338870	0.05	0.9851
OVERSCOR*MASKSIZE	3	49.7349348	16.5783116	0.79	0.5109

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X11 LIP LENGTH, SMILING

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
PASS - FAIL	-1.051	2.420	5.890
FAIL - PASS	-5.890	-2.420	1.051

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
LW - SN	-9.3968	0.3636	10.1240
LW - MW	-9.6090	0.5714	10.7518
LW - MN	-8.9352	0.9000	10.7352
SN - LW	-10.1240	-0.3636	9.3968
SN - MW	-5.9312	0.2078	6.3468
SN - MN	-5.0114	0.5364	6.0842
MW - LW	-10.7518	-0.5714	9.6090
MW - SN	-6.3468	-0.2078	5.9312
MW - MN	-5.9287	0.3286	6.5858
MN - LW	-10.7352	-0.9000	8.9352
MN - SN	-6.0842	-0.5364	5.0114
MN - MW	-6.5858	-0.3286	5.9287

Dependent Variable: X12 Nasal Root Breadth

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	46.6857143	6.6693878	1.28	0.3060
Error	22	114.7809524	5.2173160		
Corrected Total	29	161.4666667			

R-Square	C.V.	Root MSE	X12 Mean
0.289135	13.54236	2.28414	16.8667

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	4.1916851	4.1916851	0.80	0.3798
MASKSIZE	3	1.5142176	0.5047392	0.10	0.9610
OVERSCOR*MASKSIZE	3	44.3346111	14.7782037	2.83	0.0618

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X12 NASAL ROOT BREADTH

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
FAIL - PASS	-1.3496	0.3839	2.1175
PASS - FAIL	-2.1175	-0.3839	1.3496

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Simultaneous Difference Between Means	Upper Confidence Limit
MN - MW	-3.0257	0.1000	3.2257
MN - SN	-2.3077	0.4636	3.2350
MN - LW	-4.3130	0.6000	5.5130
MW - MN	-3.2257	-0.1000	3.0257
MW - SN	-2.7030	0.3636	3.4303
MW - LW	-4.5855	0.5000	5.5855
SN - MN	-3.2350	-0.4636	2.3077
SN - MW	-3.4303	-0.3636	2.7030
SN - LW	-4.7393	0.1364	5.0120
LW - MN	-5.5130	-0.6000	4.3130
LW - MW	-5.5855	-0.5000	4.5855
LW - SN	-5.0120	-0.1364	4.7393

Dependent Variable: X13 Nose Breadth

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	34.8500000	4.9785714	0.46	0.8560
Error	22	240.6166667	10.9371212		
Corrected Total	29	275.4666667			

R-Square	C.V.	Root MSE	X13 Mean
0.126513	9.307125	3.30713	35.5333

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	3.2581923	3.2581923	0.30	0.5907
MASKSIZE	3	22.3361956	7.4453985	0.68	0.5732
OVERSCOR*MASKSIZE	3	12.8549791	4.2849930	0.39	0.7601

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X13 NOSE BREADTH

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
PASS - FAIL	-2.3136	0.1964	2.7064
FAIL - PASS	-2.7064	-0.1964	2.3136

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
SN - MN	-3.349	0.664	4.676
SN - LW	-5.696	1.364	8.423
SN - MW	-2.219	2.221	6.661
MN - SN	-4.676	-0.664	3.349
MN - LW	-6.413	0.700	7.813
MN - MW	-2.968	1.557	6.083
LW - SN	-8.423	-1.364	5.696
LW - MN	-7.813	-0.700	6.413
LW - MW	-6.506	0.857	8.220
MW - SN	-6.661	-2.221	2.219
MW - MN	-6.083	-1.557	2.968
MW - LW	-8.220	-0.857	6.506

Dependent Variable: X14 Nose Length

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	184.571429	26.367347	2.22	0.0726
Error	22	261.595238	11.890693		
Corrected Total	29	446.166667			

R-Square	C.V.	Root MSE	X14 Mean
0.413683	6.739326	3.44829	51.1667

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	10.952576	10.952576	0.92	0.3476
MASKSIZE	3	124.216211	41.405404	3.48	0.0331
OVERSCOR*MASKSIZE	3	52.072740	17.357580	1.46	0.2528

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X14 NOSE LENGTH

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
FAIL - PASS	-1.9921	0.6250	3.2421
PASS - FAIL	-3.2421	-0.6250	1.9921

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
LW - MW	-3.677	4.000	11.677	
LW - MN	-1.217	6.200	13.617	
LW - SN	0.367	7.727	15.088	***
MW - LW	-11.677	-4.000	3.677	
MW - MN	-2.519	2.200	6.919	
MW - SN	-0.902	3.727	8.357	
MN - LW	-13.617	-6.200	1.217	
MN - MW	-6.919	-2.200	2.519	
MN - SN	-2.656	1.527	5.711	
SN - LW	-15.088	-7.727	-0.367	***
SN - MW	-8.357	-3.727	0.902	
SN - MN	-5.711	-1.527	2.656	

Dependent Variable: X15   Nose Protrusion

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	61.5880952	8.7982993	1.84	0.1303
Error	22	105.3785714	4.7899351		
Corrected Total	29	166.9666667			

R-Square	C.V.	Root MSE	X15 Mean
0.368865	12.60226	2.18859	17.3667

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	1.7572184	1.7572184	0.37	0.5509
MASKSIZE	3	38.8801942	12.9600647	2.71	0.0700
OVERSCOR*MASKSIZE	3	20.0000511	6.6666837	1.39	0.2717

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: X15   NOSE PROTRUSION

NOTE: This test controls the type I experimentwise error rate.

Pairwise Comparisons for OVERSCOR

Critical Value of Studentized Range= 2.933

Comparisons significant at the 0.05 level are indicated by '***'.

OVERSCOR Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
PASS - FAIL	-0.9736	0.6875	2.3486
FAIL - PASS	-2.3486	-0.6875	0.9736

Pairwise Comparisons for MASKSIZE

Critical Value of Studentized Range= 3.927

Comparisons significant at the 0.05 level are indicated by '***'.

MASKSIZE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
LW - MN	-0.4075	4.3000	9.0075
LW - MW	-0.5156	4.3571	9.2299
LW - SN	-0.0808	4.5909	9.2626
MN - LW	-9.0075	-4.3000	0.4075
MN - MW	-2.9378	0.0571	3.0521
MN - SN	-2.3645	0.2909	2.9463
MW - LW	-9.2299	-4.3571	0.5156
MW - MN	-3.0521	-0.0571	2.9378
MW - SN	-2.7046	0.2338	3.1721
SN - LW	-9.2626	-4.5909	0.0808
SN - MN	-2.9463	-0.2909	2.3645
SN - MW	-3.1721	-0.2338	2.7046

APPENDIX O

Fit Comparison of Sizes MN and MW

FIT COMPARISON OF SIZES MN AND MW

The raw data for the fit comparison of sizes MN and MW are located in the tables on the following page. All columns after the Survey Size column contain fit information. Within each column is data for up to three tests, each divided by a slash (/). The first number is the test rating for the main survey; it is highlighted. The second number is the test rating in size MN for the small survey. If the mask size tested in the main survey was MN, this number is highlighted. The third number is the test rating in size MW for the small survey. If the mask size tested in the main survey was MW, this number is highlighted. Two subjects (39 and 45) were not retested in the same size they wore in the main survey (MN); the missing information is indicated by a dash (-). All other subjects were retested.

					LEAKS				
	Survey	Nose	Nose	Nose	Cheek	Cheek			Overall
Subject	Size	Bridge	Right	Left	Right	Left	Chin	Other	Seal
37	MN	2 / 1 / 1	2 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	3 / 1 / 1	0 / 0 / 0	3 / 1 / 1
39	MN	1 / - / 2	2 / - / 1	1 / - / 1	1 / - / 1	1 / - / 1	2 / - / 1	0 / - / 0	2 / - / 1
45	MN	1 / - / 1	1 / - / 1	1 / - / 1	1 / - / 2	1 / - / 2	2 / - / 1	0 / - / 0	2 / - / 2
54	MW	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	0 / 0 / 0	1 / 1 / 2
59	MW	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	0 / 0 / 0	1 / 1 / 1

					COMFORT					
	Survey	Nose	Nose	Nose	Cheek	Cheek			Overall	Overall
Subject	Size	Bridge	Right	Left	Right	Left	Chin	Other	Comfort	Score
37	MN	1 / 2 / 1	2 / 2 / 1	2 / 2 / 1	2 / 1 / 1	2 / 1 / 1	1 / 2 / 1	0 / 0 / 0	2 / 2 / 1	P / F / P
39	MN	2 / - / 1	1 / - / 1	1 / - / 1	1 / - / 1	1 / - / 1	1 / - / 1	0 / - / 0	1 / - / 1	P / - / P
45	MN	1 / - / 1	1 / - / 1	1 / - / 1	1 / - / 2	1 / - / 2	2 / - / 1	0 / - / 0	1 / - / 1	P / - / P
54	MW	1 / 1 / 1	2 / 2 / 2	2 / 2 / 2	1 / 2 / 1	1 / - / 1	3 / 2 / 1	0 / 0 / 0	2 / 2 / 2	F / P / P
59	MW	1 / 1 / 3	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	0 / 0 / 0	1 / 1 / 2	P / P / F

APPENDIX P

Examination of Overall Score and Helmet Size

AAOM MALES

SUBJECTS WEARING HELMET SIZE L
EXAMINATION OF OVERALL SCORE AND HELMET SIZE

General Linear Models Procedure
Class Level Information

Class	Levels	Values
OVERSCOR	2	FAIL PASS

Number of observations in data set = 27

AAOM MALES
SUBJECTS WEARING HELMET SIZE L
EXAMINATION OF OVERALL SCORE AND HELMET SIZE

General Linear Models Procedure

Dependent Variable: X4 Head Breadth

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	42.8736264	42.8736264	2.94	0.0990
Error	25	365.1263736	14.6050549		
Corrected Total	26	408.0000000			

R-Square	C.V.	Root MSE	X4 Mean
0.105082	2.481595	3.82166	154.000

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
OVERSCOR	1	42.8736264	42.8736264	2.94	0.0990

APPENDIX Q

Principal Component Analysis Results

AAOM MALES

30% OF DATA (ELEMENTS 1-240)

Principal Component Analysis

Eigenvalues of the Correlation Matrix

	Eigenvalue	Difference	Proportion	Cumulative
PRIN1	52.2562	19.7676	0.108867	0.10887
PRIN2	32.4886	1.7040	0.067685	0.17655

AAOM MALES
30% OF DATA (ELEMENTS 1-240)

Principal Component Analysis

Eigenvectors

	PRIN1	PRIN2
C1	0.043597	0.024319
C2	0.047066	0.083025
C3	0.039362	0.035977
C4	0.047465	0.020467
C5	0.056740	0.012019
C6	0.055552	-.004234
C7	0.045928	-.015009
C8	0.046764	-.024493
C9	0.055138	-.039335
C10	0.059181	-.051761
C11	0.061954	-.056386
C12	0.066509	-.038942
C13	0.046662	-.009940
C14	0.037594	-.004381
C15	0.052495	-.006712
C16	0.063127	-.020822
C17	0.054160	-.027034
C18	0.050097	-.028438
C19	0.048049	-.024226
C20	0.032037	-.003506
C21	0.012244	0.006939
C22	0.013664	0.004253
C23	0.037772	-.007476
C24	0.065371	-.019027
C25	0.071208	-.020592
C26	0.071763	-.026256
C27	0.062742	-.028428
C28	0.073710	-.032697
C29	0.074558	-.043227
C30	0.073707	-.069279
C31	0.038266	-.064165
C32	0.030389	-.056622
C33	0.056971	-.053132
C34	0.037841	-.008607
C35	0.025860	0.019054
C36	0.030729	0.032720
C37	0.051311	0.031723
C38	0.054258	-.003889
C39	0.053902	-.033440
C40	0.063459	-.044944
C41	0.044803	-.027124
C42	0.060036	0.004276
C43	0.051595	-.001970

	PRIN1	PRIN2
C44	0.050036	-.032304
C45	0.054140	-.032271
C46	0.052075	-.004673
C47	0.044510	0.027881
C48	0.055671	0.019005
C49	0.051768	-.049450
C50	0.030588	-.061940
C51	0.046419	-.045305
C52	0.050580	-.031071
C53	0.045802	-.027044
C54	0.064285	-.020591
C55	0.069486	-.009040
C56	0.059485	-.032448
C57	0.050513	-.051625
C58	0.025361	-.040982
C59	0.031956	-.007138
C60	0.037466	0.003751
C61	0.052723	-.004684
C62	0.076406	-.048921
C63	0.074657	-.082785
C64	0.070621	-.096326
C65	0.062392	-.076336
C66	0.060990	-.077924
C67	0.026761	-.047940
C68	0.026851	-.038890
C69	0.069413	-.062622
C70	0.071178	-.076192
C71	0.067570	-.079496
C72	0.066318	-.057633
C73	0.067495	-.039395
C74	0.060806	-.037372
C75	0.052626	-.032804
C76	0.062100	-.012288
C77	0.051812	-.015321
C78	0.037250	-.039933
C79	0.040262	-.059602
C80	0.062248	-.101235
C81	0.058956	-.082160
C82	0.047145	-.036922
C83	0.061123	-.028627
C84	0.066604	0.018361
C85	0.066937	0.076957
C86	0.064108	0.087285
C87	0.066045	0.059657
C88	0.049882	-.007917
C89	0.053495	-.022876
C90	0.066626	-.058722
C91	0.065967	-.075969
C92	0.053889	-.072198
C93	0.044226	-.040391
C94	0.026649	0.017641

	PRIN1	PRIN2
C95	0.016243	0.036175
C96	0.029554	0.038004
C97	0.065326	0.010158
C98	0.061347	-.020833
C99	0.078267	-.042679
C100	0.085880	-.079100
C101	0.080263	-.093097
C102	0.078858	-.084873
C103	0.081026	-.036485
C104	0.054472	0.031298
C105	0.063237	0.014423
C106	0.072806	-.007234
C107	0.073028	-.025100
C108	0.075982	-.036471
C109	0.090242	-.053058
C110	0.078038	-.060284
C111	0.060652	-.057103
C112	0.060831	-.047613
C113	0.071168	-.022422
C114	0.082774	0.033390
C115	0.072709	0.084561
C116	0.065441	0.088223
C117	0.080996	0.050332
C118	0.101701	-.034343
C119	0.103708	-.082203
C120	0.092184	-.091830
C121	0.075162	-.083516
C122	0.064472	-.073714
C123	0.058914	-.060503
C124	0.060912	-.045983
C125	0.082676	-.038849
C126	0.088907	-.040617
C127	0.079117	-.056021
C128	0.075884	-.065473
C129	0.077871	-.066100
C130	0.080224	-.059355
C131	0.081100	-.052696
C132	0.082622	-.046929
C133	0.078321	-.007126
C134	0.069663	0.064254
C135	0.059856	0.084513
C136	0.064343	0.076375
C137	0.084245	0.023862
C138	0.085638	-.047428
C139	0.077871	-.074101
C140	0.071170	-.075942
C141	0.063552	-.059309
C142	0.064120	-.011111
C143	0.061824	0.034381
C144	0.061351	0.059937
C145	0.076050	0.067064

	PRIN1	PRIN2
C146	0.076376	0.084910
C147	0.057802	0.090640
C148	0.051052	0.088559
C149	0.052124	0.078822
C150	0.058512	0.076612
C151	0.049700	0.070269
C152	0.039908	0.061917
C153	0.037065	0.058882
C154	0.041027	0.061929
C155	0.049161	0.067884
C156	0.056555	0.067953
C157	0.060788	0.059386
C158	0.056840	0.044579
C159	0.032905	0.037218
C160	0.017188	0.032746
C161	0.013840	0.037857
C162	0.016585	0.049372
C163	0.032703	0.083374
C164	0.056218	0.101251
C165	0.065516	0.085057
C166	0.071873	0.070679
C167	0.075542	0.069971
C168	0.068763	0.066652
C169	0.053016	0.059065
C170	0.039142	0.046149
C171	0.023142	0.033857
C172	0.023457	0.054896
C173	0.054534	0.077090
C174	0.075029	0.086791
C175	0.086916	0.089132
C176	0.091915	0.084919
C177	0.094579	0.079136
C178	0.094213	0.068970
C179	0.085349	0.045972
C180	0.053204	0.001222
C181	0.046502	0.058238
C182	0.055558	0.115001
C183	0.065494	0.117850
C184	0.073182	0.111100
C185	0.080040	0.102863
C186	0.083942	0.086606
C187	0.081322	0.059123
C188	0.076838	-.008238
C189	0.066878	-.049579
C190	0.072495	0.025154
C191	0.075813	0.080462
C192	0.072450	0.098876
C193	0.073639	0.102147
C194	0.075968	0.098408
C195	0.078205	0.089273
C196	0.063962	0.065209

	PRIN1	PRIN2
C197	0.012566	0.016690
C198	0.025546	0.049797
C199	0.048693	0.071574
C200	0.062241	0.081046
C201	0.070923	0.082613
C202	0.078872	0.076675
C203	0.084920	0.060174
C204	0.084413	0.034331
C205	0.065137	0.005298
C206	0.020183	-.021792
C207	0.018418	0.022941
C208	0.023886	0.064928
C209	0.029953	0.083457
C210	0.040282	0.089070
C211	0.061225	0.079365
C212	0.075854	0.033663
C213	0.062363	-.032472
C214	0.040293	-.044847
C215	0.032359	-.014249
C216	0.025759	0.017449
C217	0.016412	0.034673
C218	0.008389	0.042316
C219	0.004484	0.047813
C220	0.008404	0.060734
C221	0.003563	0.045515
C222	-.019885	0.014762
C223	-.022390	0.007647
C224	-.013260	0.017268
C225	-.000495	0.023226
C226	0.015769	0.025116
C227	0.033395	0.021436
C228	0.045381	0.008902
C229	0.045018	-.020287
C230	0.012439	-.025201
C231	-.017096	-.004076
C232	-.031605	0.014371
C233	-.035916	0.022467
C234	-.035698	0.022364
C235	-.032319	0.019439
C236	-.021472	0.011913
C237	0.003516	-.013717
C238	0.030467	-.043905
C239	0.027337	-.048677
C240	0.007946	-.035803
T1	-.040158	-.013871
T2	-.053760	-.017081
T3	-.055592	-.015224
T4	-.049223	-.006804
T5	-.048396	0.000955
T6	-.040923	-.007166
T7	-.061410	-.053933

	PRIN1	PRIN2
T8	-.059334	-.036907
T9	-.063853	-.005048
T10	-.035346	0.012200
T11	-.040418	-.025276
T12	-.029263	0.014015
T13	0.000740	0.023200
T14	-.005228	0.045220
T15	0.012503	0.041626
T16	-.026717	0.023160
T17	0.002852	0.035516
T18	-.008072	0.070265
T19	0.026728	0.111582
T20	0.008309	0.055846
T21	-.021381	-.000518
T22	-.010233	0.002908
T23	-.032523	0.010792
T24	0.007256	0.011730
T25	0.021466	0.050978
T26	0.006340	0.036518
T27	0.003052	0.021811
T28	-.045275	0.032664
T29	-.038593	0.002231
T30	-.002606	-.001525
T31	0.000009	-.009132
T32	0.015402	-.013806
T33	0.000784	-.044406
T34	-.025939	-.096685
T35	0.028273	0.006454
T36	0.002906	-.046524
T37	-.005344	-.020674
T38	0.025370	-.038379
T39	0.004057	-.009704
T40	0.003281	-.004650
T41	0.010723	-.011064
T42	0.004040	-.012432
T43	0.011868	-.008649
T44	0.035136	0.059980
T45	0.019529	0.016105
T46	0.030819	0.013055
T47	0.052835	0.021743
T48	0.062962	-.074416
T49	0.025648	-.028221
T50	0.008930	-.032660
T51	-.012634	-.034195
T52	0.016671	-.015343
T53	-.006189	-.081896
T54	0.033645	-.003064
T55	0.026792	0.028982
T56	0.032161	-.024486
T57	0.041164	-.024855
T58	0.037753	-.060346

	PRIN1	PRIN2
T59	0.048491	-.032741
T60	0.003903	-.026713
T61	0.006982	-.004196
T62	0.003653	0.026520
T63	0.023624	0.021728
T64	0.011886	-.011613
T65	0.009572	-.038012
T66	-.002223	-.066009
T67	-.009984	-.057035
T68	-.004636	-.011395
T69	-.037656	-.015372
T70	0.035710	-.018862
T71	0.005609	-.015599
T72	0.019305	-.002342
T73	0.003285	0.024895
T74	-.037609	0.021615
T75	-.047272	0.033301
T76	0.004800	-.007906
T77	0.007480	0.011907
T78	0.003255	-.021529
T79	0.022468	0.023753
T80	0.000709	0.011233
T81	0.023377	0.041890
T82	0.029070	0.051311
T83	0.005550	0.028787
T84	0.001891	0.023093
T85	0.026284	-.011960
T86	-.000531	0.012061
T87	-.030578	0.034559
T88	0.010244	0.011666
T89	0.033205	0.015421
T90	0.029843	0.011762
T91	0.012005	0.003708
T92	-.033374	0.027308
T93	0.015939	-.006562
T94	-.032607	0.003455
T95	-.037219	0.028394
T96	-.011206	0.049493
T97	-.035225	0.042533
T98	-.041488	0.032625
T99	-.057097	0.036503
T100	-.008688	0.016934
T101	0.004090	0.012723
T102	0.001049	0.019644
T103	-.023068	0.046089
T104	-.059219	0.089994
T105	-.065284	0.048912
T106	-.053700	0.024906
T107	-.054678	0.028411
T108	-.007968	0.013456
T109	0.008246	-.000185
T110	0.003705	-.013369
T111	-.006863	0.018317
T112	-.011072	0.019482
T113	-.038820	0.052882
T114	-.039044	0.068505
T115	-.006952	0.024371
T116	-.000513	0.022283
T117	-.016063	0.036309
T118	-.013517	0.048498
T119	0.014517	0.028174
T120	-.014291	0.050426
T121	-.024938	0.014183
T122	0.013151	0.030778
T123	0.005202	0.023153
T124	-.011042	-.003851
T125	-.023163	0.009251
T126	0.005429	-.003796
T127	0.009214	0.009678
T128	0.008076	0.014007
T129	-.014270	0.004439
T130	-.009290	-.003724
T131	-.000617	-.001962
T132	-.001204	0.006743
T133	0.014913	0.045581
T134	0.002518	0.003083
T135	0.012298	-.003305
T136	-.008131	0.008020
T137	-.002191	0.016383
T138	-.004197	-.014831
T139	-.028418	-.005525
T140	-.002580	0.009700
T141	0.012597	0.047208
T142	0.005116	0.013826
T143	0.029491	-.024211
T144	0.048940	-.081858
T145	-.017258	0.021271
T146	-.036506	0.016694
T147	-.025980	-.000401
T148	-.032453	0.003135
T149	0.000823	0.052009
T150	-.015618	0.033022
T151	-.014760	0.018100
T152	0.005031	0.045045
T153	0.024688	0.116908
T154	0.002415	0.098744
T155	-.006674	0.063715
T156	-.011556	0.042213
T157	-.011537	0.022391
T158	-.004209	0.012160
T159	-.020274	0.067426
T160	0.004272	0.058931
T161	0.019681	0.049525
T162	0.051493	0.075007
T163	0.012033	-.007100
T164	0.002758	0.000848
T165	0.009995	-.015416
T166	-.027390	-.000640
T167	-.025683	0.018987
T168	-.021502	0.038665
T169	0.042969	-.032043
T170	0.005728	0.043241
T171	-.027334	-.042131
T172	-.006653	0.023326
T173	0.000715	-.009468
T174	0.005126	0.029546
T175	0.021953	0.040783
T176	0.034792	0.005888
T177	0.019469	0.011186
T178	-.004569	0.033364
T179	-.028497	0.030865
T180	0.021128	0.062097
T181	0.014828	-.001865
T182	-.006789	0.005869
T183	-.011570	0.030135
T184	-.000130	0.043712
T185	0.004334	0.017795
T186	0.009964	0.019627
T187	0.054119	-.085453
T188	0.006907	-.001862
T189	0.000183	-.033642
T190	0.021359	-.019843
T191	-.004784	-.026251
T192	0.040971	-.034908
T193	0.011299	-.006501
T194	-.006188	0.007263
T195	-.019683	-.003969
T196	0.035603	-.003263
T197	-.029102	-.001781
T198	-.043580	0.051026
T199	-.004379	0.036561
T200	0.007540	0.030003
T201	-.008501	-.012298
T202	-.034367	-.018744
T203	-.002169	0.023408
T204	0.007315	0.000703
T205	0.015215	-.014381
T206	0.012772	-.010048
T207	0.013454	-.041019
T208	0.032853	-.047606
T209	0.033435	-.057229
T210	0.028453	-.058315
T211	0.024766	-.013159

	PRIN1	PRIN2
T212	0.010185	-.037075
T213	0.010410	0.011160
T214	0.011641	0.006166
T215	-.005591	-.015080
T216	-.006336	-.001768
T217	-.012829	-.006475
T218	-.023207	-.012357
T219	-.041240	-.022023
T220	-.034211	0.012628
T221	-.035384	-.000569
T222	-.038622	-.042810
T223	-.046262	-.097236
T224	-.023686	-.031009
T225	-.003241	-.021665
T226	0.028360	-.003681
T227	0.025147	-.002559
T228	0.045776	-.013086
T229	-.018137	0.016879
T230	0.005922	0.029313
T231	0.010680	0.033524
T232	0.049783	-.013624
T233	0.019996	-.050575
T234	-.022667	-.018862
T235	-.048492	0.008692
T236	-.064332	0.027491
T237	-.029784	0.007807
T238	-.028529	-.018977
T239	-.014181	-.023839
T240	-.028532	-.064280

APPENDIX R

Euclidean Distance Maxtrix Analysis Results

EDMA RESULTS

Variation Due to Mask Size

Males with Good Fits - Ratio of SN to MN

All significant distances that were found in the comparison of good fits in a size SN to good fits in a size MN were distances between a facial landmark and a mask landmark. None were anthropometric differences.

The distance from Upper Left Rivet to Pronasale is 30%-39% larger for males wearing SN than for males wearing MN.

The distances from Top-Mid Mask to Min Right, Top-Mid Mask to Pronasale, Min Right to Min Left, Max Bottom-Left to Promenton, Max Bottom-Left to Supramenton are 20%-29% larger for males wearing SN than for males wearing MN.

The distance from Top-Mid Mask to Mid-Nosebridge is 40%-49% larger for males wearing SN than for males wearing MN.

The distances from Bottom-Mid Mask to Supramenton, Min Left to Left InfraOrbitale, Max Right to Right InfraMalar are 30%-39% smaller for males wearing SN than for males wearing MN.

The distances from Min Right to Right InfraOrbitale, Max Right to Max Bottom-Right, Max Left to Max Bottom-Left, Max Left to Left InfraMalar, Max Bottom-Right to Right Alare, Max Bottom-Right to Right InfraMalar, Max Bottom-Right to Right InfraOrbitale, Max Bottom-Left to Left InfraMalar are 20%-29% smaller for males wearing SN than for males wearing MN.

Males with Good Fits - Ratio of SN to MW

Comparing males in size SN with good fits to males in size MW with good fits again showed that all of the differences were due to the mask differences. No anthropometric significant differences were found.

Several distances are 20%-29% smaller for males wearing SN than for males wearing MW. They are: Upper Right Rivet to Mid-Nosebridge, Upper Left Rivet to Mid-Nosebridge, Upper Right Pentagon to Mid-Nosebridge, Upper Right Pentagon to Pronasale, Lower Right Pentagon to Mid-Nosebridge, Lower Right Pentagon to Pronasale, Lower Left Pentagon to Pronasale, Bottom-Mid Mask to Left Alare, Min Right to Mid-Nosebridge, Min Right to Glabella, Min Left to Left InfraOrbitale, Max Right to Right Alare, Max Right to Right InfraOrbitale, Max Left to Left InfraOrbitale, Max Bottom-Right to Right Alare, Max Bottom-Right to Right InfraMalar, Max Bottom-Right to Right InfraOrbitale, Max Bottom-Left to Left InfraOrbitale, and Max Bottom-Left to Left InfraMalar.

The distance from Min Right to Sellion is 30%-39% smaller for males wearing SN than for males wearing MW.

The distances from Bottom-Mid Mask to Supramenton, Max Right to Right InfraMalar, and Max Left to Left InfraMalar are 40%-49% smaller for males wearing SN than for males wearing MW.

The distances from Upper Left Pentagon to Promenton, Lower Right Pentagon to Bottom-Mid Mask, Lower Left Pentagon to Promenton, and Top-Mid Mask to Right InfraOrbitale are 20%-29% larger for males wearing SN than for males wearing MW.

The distances from Top-Mid Mask to Mid-Nosebridge, Min Right to Right Alare, and Min Right to Right InfraMalar are 30%-39% larger for males wearing SN than for males wearing MW.

The distance from Min Left to Left Alare is 40%-49% larger for males wearing SN than for males wearing MW.

Males with Good Fits - Ratio of SN to LW Sizes

In comparing males in size SN with good fits to the one male in size LW with good fit the following anthropometric differences were found to be significant: Right Alare to Supramenton, Right Tragion to Right Zygion, Pronasale to Promenton, and Pronasale to Supramenton. These distances are all 20%-29% smaller for males wearing SN masks than for the one male wearing the LW size.

Several distances are 20%-29% smaller for males wearing SN masks than for the male wearing the LW size. They are: Upper Right Rivet to Upper Right Pentagon , Upper Right Rivet to Top-Mid Mask, Upper Left Rivet to Top-Mid Mask, Upper Right Pentagon to Top-Mid Mask, Upper Left Pentagon to Top-Mid Mask, Lower Right Pentagon to Promenton, Top-Mid Mask to Pronasale, Top-Mid Mask to Supramenton, Min Right to Mid-Nosebridge, Min Right to Pronasale, Min Right to Promenton, Min Right to Supramenton, Min Left to Left Alare, Min Left to Supramenton, Max Right to Max Bottom-Right, Max Left to Max Bottom-Left, Right Alare to Supramenton, Right Tragion to Right Zygion, Pronasale to Promenton, and Pronasale to Supramenton.

The distances from Top-Mid Mask to Mid-Nosebridge, and Bottom-Mid Mask to Promenton are 30%-39% smaller for males wearing SN masks than for the male wearing the LW size.

The distances from Upper Right Rivet to Pronasale, Upper Left Rivet to Mid-Nosebridge, and Upper Left Rivet to Pronasale are 20%-29% larger for males wearing SN masks than for the male wearing the LW size.

The distance from Upper Right Rivet to Mid-Nosebridge is 30%-39% larger for males wearing SN masks than for the male wearing the LW size.

The distances from Top-Mid Mask to Glabella, and Top-Mid Mask to Sellion are 40%-49% larger for males wearing SN masks than for the male wearing the LW size.

Males with Good Fits - Ratio of MN to MW Sizes

There was a significant anthropometric difference found when comparing males with good fits in the MN size to males with good fits in the MW size. That difference was Glabella to Sellion which was 20%-29% smaller for males wearing the MN size than for the males wearing the MW size. However this difference would not appear to have any significance in determining mask width for sizing purposes.

Several distances are 20%-29% smaller for males wearing the MN size than for the males wearing the MW size. They are: Upper Left Rivet to Min Right , Upper Left Rivet to Mid-Nosebridge, Upper Left Rivet to Pronasale, Top-Mid Mask to Min Right , Top-Mid Mask to Min Left , Bottom-Mid Mask to Max Bottom-Left, Min Right to Min Left , Min Right to Glabella, Min Right to Sellion, Min Right to Pronasale, Max Right to Right InfraMalar, Max Left to Left InfraMalar, Max Bottom-Left to Supramenton, and Glabella to Sellion.

The distances from Lower Right Pentagon to Lower Left Pentagon , and Min Right to Mid-Nosebridge are 30%-39% smaller for males wearing the MN size than for the males wearing the MW size.

The distances from Lower Right Pentagon to Bottom-Mid Mask, Max Right to Max Bottom-Right, and Max Left to Max Bottom-Left are 20%-29% larger for males wearing the MN size than for the males wearing the MW size.

The distances from Min Right to Right Alare, Min Right to Right InfraMalar, Min Right to Right InfraOrbitale, and Min Left to Left Alare are 30%-39% larger for males wearing the MN size than for the males wearing the MW size.

Males with Good Fits - Ratio of MN to LW Sizes

The only anthropometric difference between the males in size MN with good fits and the male in size LW with good fit is the distance from Glabella to Sellion which is 20%-29% smaller for the males wearing MN than for the one male wearing the LW size.

Several distances are 20%-29% smaller for the males wearing MN than for the male wearing the LW size. They are: Upper Left Rivet to Top-Mid Mask, Upper Left Rivet to Min Right, Upper Right Pentagon to Top-Mid Mask, Upper Left Pentagon to Top-Mid Mask, Lower Right Pentagon to Lower Left Pentagon, Lower Right Pentagon to Promenton, Lower Left Pentagon to Promenton, Top-Mid Mask to Min Right, Top-Mid Mask to Min Left, Top-Mid Mask to Right Alare, Top-Mid Mask to Left Alare, Top-Mid Mask to Promenton, Bottom-Mid Mask to Max Bottom-Left, Bottom-Mid Mask to Promenton, Min Right to Min Left, Min Right to Right Alare, Min Right to Left Alare, Min Right to Supramenton, Min Left to Mid-Nosebridge, Min Left to Left Alare, Min Left to Left InfraOrbitale, Max Bottom-Left to Promenton, Max Bottom-Left to Supramenton, and Glabella to Sellion.

The distances from Min Right to Mid-Nosebridge, Min Right to Pronasale, and Min Left to Pronasale are 30%-39% smaller for the males wearing MN than for the male wearing the LW size.

The distance from Top-Mid Mask to Pronasale is 40%-49% smaller for the males wearing MN than for the male wearing the LW size.

The distance from Top-Mid Mask to Mid-Nosebridge is 60%-69% smaller for the males wearing MN than for the male wearing the LW size.

The distances from Upper Right Rivet to Sellion, Upper Left Rivet to Promenton, Upper Left Rivet to Sellion, and Max Left to Left InfraMalar are 20%-29% larger for the males wearing MN than for the male wearing the LW size.

The distance from Min Right to Right InfraOrbitale is 30%-39% larger for the males wearing MN than for the male wearing the LW size.

The distances from Upper Right Rivet to Mid-Nosebridge, Bottom-Mid Mask to Supramenton, and Max Right to Right InfraMalar are 40%-49% larger for the males wearing MN than for the male wearing the LW size.

The distances from Top-Mid Mask to Glabella, and Top-Mid Mask to Sellion are 50%-59% larger for the males wearing MN than for the male wearing the LW size.

Males with Good Fits - Ratio of MW to LW Sizes

There are two significant anthropometric differences between the males with good fits in size MW and the male with good fit in size LW. The distance from Pronasale to Supramenton is 20%-29% smaller for the males wearing the MW mask than for the male wearing the LW size. However, the distance from Right Zygion to Right InfraMalar is 20%-29% larger for the males wearing the MW mask than for the male wearing the LW size. The distance from Right Zygion to Right InfraMalar should not make a difference in mask size.

Several distances are 20%-29% smaller for the males wearing the MW mask than for the male wearing the LW size. They are: Upper Right Rivet to Promenton, Upper Right Rivet to Supramenton, Upper Left Rivet to Promenton, Upper Left Rivet to Supramenton, Upper Right Pentagon to Promenton, Upper Right Pentagon to Supramenton, Upper Left Pentagon to Promenton, Upper Left Pentagon to Supramenton, Lower Right Pentagon to Supramenton, Lower Left Pentagon to Bottom-Mid Mask, Lower Left Pentagon to Supramenton, Top-Mid Mask to Right Alare, Top-Mid Mask to Left Alare, Top-Mid Mask to Right InfraMalar, Top-Mid Mask to Right InfraOrbitale, Top-Mid Mask to Promenton, Top-Mid Mask to Supramenton, Min Right to Pronasale, Min Right to Promenton, Min Left to Promenton, Min Left to Left InfraMalar, Max Right to Max Bottom-Right, Max Right to Promenton, Max Right to Supramenton, and Pronasale to Supramenton.

The distances from Lower Right Pentagon to Bottom-Mid Mask, Lower Right Pentagon to Promenton, Lower Left Pentagon to Promenton, Top-Mid Mask to Pronasale, Min Right to Right InfraMalar, Min Right to Supramenton, Min Left to Pronasale, and Min Left to Supramenton are 30%-39% smaller for the males wearing the MW mask than for the male wearing the LW size.

The distance from Min Right to Right Alare is 40%-49% smaller for the males wearing the MW mask than for the male wearing the LW size.

The distances from Top-Mid Mask to Mid-Nosebridge, and Min Left to Left Alare are 50%-59% smaller for the males wearing the MW mask than for the male wearing the LW size.

Several distances are 20%-29% larger for the males wearing the MW mask than for the male wearing the LW size. They are: Upper Right Rivet to Glabella, Upper Right Rivet to Pronasale, Upper Left Rivet to Glabella, Upper Left Rivet to Sellion, Upper Right Pentagon to Mid-Nosebridge, Upper Right Pentagon to Pronasale, Upper Left Pentagon to Mid-Nosebridge, Upper Left Pentagon to Pronasale, Lower Right Pentagon to Pronasale, Min Right to Glabella, Min Left to Glabella, Min Left to Sellion, Min Left to Left InfraOrbitale, Max Right to Right Zygion, Max Right to Right InfraOrbitale, and Right Zygion to Right InfraMalar.

The distances from Upper Right Rivet to Sellion, and Min Right to Sellion are 30%-39% larger for the males wearing the MW mask than for the male wearing the LW size.

The distances from Upper Left Rivet to Mid-Nosebridge, Top-Mid Mask to Sellion, and Max Left to Left InfraMalar are 40%-49% larger for the males wearing the MW mask than for the male wearing the LW size.

The distances from Upper Right Rivet to Mid-Nosebridge, Top-Mid Mask to Glabella, Bottom-Mid Mask to Supramenton, and Max Right to Right InfraMalar are 50%-59% larger for the males wearing the MW mask than for the male wearing the LW size.

Variation Affecting Overall Score Within a Size

Males in SN

All significant differences found were non-anthropometric. The distance from Top-Mid Mask to Mid-Nosebridge is 20%-29% larger for the good fits over the bad fits. The distance from Bottom-Mid Mask to Promenton is 30%-39% larger for good fits over the bad fits. That means the men in SN who have good fits are wearing their masks differently on their faces than the men in SN who have poor fits.

Males in MN

There was only one significant difference between good fits and bad fits for males in size MN. It was the distance from Bottom-Mid Mask to Promenton which was 19.5% larger for the men with good fits in MN over the poor fits. Again, this was not an anthropometric difference. This means the men in MN who have good fits are wearing their masks differently on their faces than the men in MN who have poor fits.

Males in MW

While there were many significant differences found between the males in size MW with good fits and those with poor fits, only one was anthropometric. That one significant anthropometric difference was the distance from Promenton to Supramenton which was 20%-29% smaller for the good fits over the poor fits. It is possible that this is important. However, only one subject received a poor fit because of lack of comfort in the chin region, and he should have been in the LW size by the T.O. criteria. More importantly, the large number of non-anthropometric differences shows that the men in MW with good fits are wearing their masks differently on their faces than the men in MW with poor fits. All significant differences include non-anthropometric differences follow.

The distances from Lower Left Pentagon to Promenton, Bottom-Mid Mask to Promenton, and Min Right to Right Alare are 30%-39% smaller for men in MW with good fits over men in MW with poor fits.

Several distances are 20% - 29% smaller for the good fits in MW over the poor fits. They are: Upper Left Rivet to Promenton, Upper Right Pentagon point to Promenton, Upper Left Pentagon to Promenton, Upper Left Pentagon to Supramenton, Lower Right Pentagon to Promenton, Lower Left Pentagon to Supramenton, Top-Mid Mask to Mid-Nosebridge, Min Right to Right InfraMalar, Min Left to Left Alare, and Promenton to Supramenton.

The distances from Max Right to Right InfraMalar, and Max Left to Left InfraMalar are 20% - 29% larger for the good fits in MW over the poor fits.

Males in LW

There are only 2 subjects in LW; 1 with a good fit and 1 with a poor fit. Thus the variance of the data is much larger than the other sizes, yet there is still only one anthropometric significant difference at 20%-29% between the two subjects (the distance from Right InfraMalar to Right InfraOrbitale) which is not considered to have impacted the fit. All of the significant differences are listed below. All of the other differences combine to show that the male with a good fit wears his mask differently on his face than the male with a poor fit.

The distances from Top-Mid Mask to Glabella, and Bottom-Mid Mask to Supramenton are 50%-59% smaller for good fit in LW over the poor fit.

The distance from Top-Mid Mask to Sellion is 40%-49% smaller for the good fit in LW over the poor fit.

The distances from Upper Right Rivet to Mid-Nosebridge, Upper Left Rivet to Mid-Nosebridge, Bottom-Mid Mask to Promenton, and Mid-Nosebridge to Pronasale are smaller by 30% - 39% for the good fit in LW over the poor fit.

The distances from Upper Right Rivet to Glabella, Upper Right Rivet to Sellion, Upper Left Rivet to Sellion, Upper Right Pentagon to Mid-Nosebridge, Upper Left Pentagon to Mid-Nosebridge, Lower Left Pentagon to Supramenton, Max Right to Right InfraMalar, and Right InfraMalar to Right InfraOrbitale are smaller by 20% - 29% for the good fit in LW over the poor fit.

The distance from Top-Mid Mask to Mid-Nosebridge is larger by 30% for the good fit in LW over the poor fit.

Females in SN

Even though it is not known how valid our data are for the females in this study, the ratios for the females in size SN with good fits to poor fits were studied. The only significant distances are from Bottom-Mid Mask to Promenton, and Min Left to Left InfraOrbitale which are 20%-29% larger for the good fits over the poor fits for females in mask size SN.

This shows that the females in the SN with good fits are wearing their masks differently on their faces than the women in SN with poor fits.

NOTE: The masks are also rotated slightly to the right. Possible explanation: Systematically tightening the mask to the helmet in one direction; or possibly the helmet is too loose allowing the mask to slip on the face.

APPENDIX S

XYZ Coordinates of Mask Landmarks for Current and New Sizes

LW

Landmark Number	X	Y	Z
3	-15.23	42.86	32.80
4	15.23	42.86	32.80
5	-9.06	19.17	26.67
6	9.06	.19.17	26.67
14	0.00	113.71	0.00
15	0.00	0.00	0.00
16	-21.95	86.46	-11.13
17	21.95	86.46	-11.13
18	-50.74	39.38	-28.10
19	50.74	39.38	-28.10
20	-43.77	11.79	-28.42
21	43.77	11.79	-28.42

MW

Landmark Number	X	Y	Z
3	-15.86	36.62	27.17
4	15.86	36.62	27.17
5	-9.81	12.31	18.40
6	9.81	12.31	18.40
14	0.00	99.90	0.00
15	0.00	0.00	0.00
16	-21.16	73.53	-14.39
17	21.16	73.53	-14.39
18	-47.53	32.42	-33.26
19	47.53	32.42	-33.26
20	-44.18	11.18	-30.10
21	44.18	11.18	-30.10

MN

Landmark Number	X	Y	Z
3	-13.91	44.03	27.63
4	13.91	44.03	27.63
5	-6.46	19.59	21.72
6	6.46	19.59	21.72
14	0.00	98.77	0.00
15	0.00	0.00	0.00
16	-16.21	79.66	-10.35
17	16.21	79.66	-10.35
18	-45.85	33.80	-29.41
19	45.85	33.80	-29.41
20	-37.21	7.05	-23.85
21	37.21	7.05	-23.85

SN

Landmark Number	X	Y	Z
3	-16.69	42.75	31.35
4	16.69	42.75	31.35
5	-8.07	17.08	24.03
6	8.07	17.08	24.03
14	0.00	94.23	0.00
15	0.00	0.00	0.00
16	-21.08	70.92	-14.32
17	21.08	70.92	-14.32
18	-45.92	30.30	-31.60
19	45.92	30.30	-31.60
20	-40.88	10.14	-27.26
21	40.88	10.14	-27.26

SW

Landmark Number	X	Y	Z
3	-16.6	40.4	21.6
4	16.6	40.4	21.6
5	-10.5	5.4	10.1
6	10.5	5.4	10.1
14	0.0	86.1	0.0
15	0.0	0.0	0.0
16	-20.4	60.5	-17.7
17	20.4	60.5	-17.7
18	-44.3	25.4	-38.5
19	44.3	25.4	-38.5
20	-44.6	10.6	-31.8
21	44.6	10.6	-31.8

XSN

Landmark Number	X	Y	Z
3	-19.5	41.6	35.2
4	19.5	41.6	35.2
5	-9.7	14.6	26.3
6	9.7	14.6	26.3
14	0.0	89.6	0.0
15	0.0	0.0	0.0
16	-26.0	62.1	-18.2
17	26.0	62.1	-18.2
18	-45.9	26.8	-33.8
19	45.9	26.8	-33.8
20	-44.6	13.1	-30.7
21	44.6	13.1	-30.7

LN

Landmark Number	X	Y	Z
3	-11.1	45.3	23.9
4	11.1	45.3	23.9
5	-4.9	22.1	19.4
6	4.9	22.1	19.4
14	0.0	103.3	0.0
15	0.0	0.0	0.0
16	-11.3	88.4	-6.4
17	11.3	88.4	-6.4
18	-45.8	37.3	-27.2
19	45.8	37.3	-27.2
20	-33.5	4.0	-20.4
21	33.5	4.0	-20.4